# METALS AND ALLOYS

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TREATMENT APPLICATION



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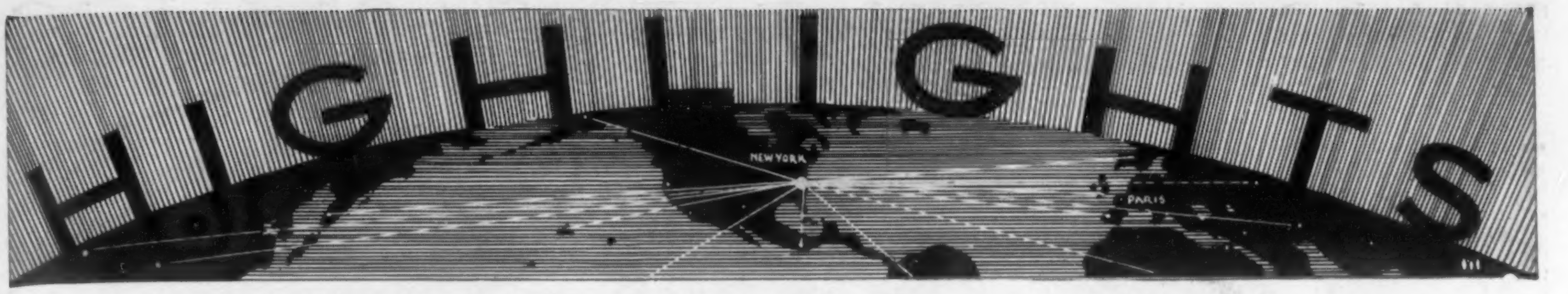
### ARTICLES



### CURRENT METALLURGICAL ABSTRACTS




## Written by the Abstract Section Editors and the Editorial Staff

**DO YOU want to know what metallurgical engineers are saying, the world over? Look in the Current Metallurgical Abstracts. Here are some of the points covered by authors whose articles are abstracted in this issue.**

### Do You Remember the Boronized Copper of 25 Years Ago?

According to Andrieux (page MA 175 R 5) it's just like rolling off a log to make boron alloys. There should be interesting possibilities in such alloys, but who is interested in studying them? We often feel sorry for the poor elements that everybody can make and use because they have no strong group watching out for applications. Ni, Al, Mo, V, Sn, etc. are favorite children of their proud parents, but Si, B, Mn and others, so plentiful as to be decidedly cheap, are pretty much step-children. There are some advantages in being the protege of a monopoly or near-monopoly.—H.W.G.

### Molding with Sand Cores Now More Precise

Precision molding with sand cores has reached the point where Hudson (page MA 176 L 2) finds it necessary to take into consideration the normal expansion, as well as the other high-temperature properties of the cores.—H.W.G.

### Cast Iron

Abstracts by the dozen on everything about cast iron from description of plants to form of graphite and even silicate "slimes." Take a look (page MA 179 L 2, 4, 5 and 7) for lots of information on this general subject.—C.H.H.

### A Suggestion Regarding Brass Shims

Berg's (page MA 182 R 2) experiments with brass shims between a key and its keyway raise the question whether a similar cushioning layer might not well be tried in cases of force fits and other joints intended to be rigid but actually having infinitesimal play. The formation of finely divided red rust from the oxidation of worn-off particles—so-called "bleeding"—from a supposedly tight joint would indicate cases where this plan might be tried.—H.W.G.

### Heat-Treated Metals May Talk

Maybe the talking film of the processes going on in heat-treated metals is coming, telling their own story of their suffering. The beginning seems to be made, although so far in tones beyond our conception (page MA 184 R 2).—M.H.

### Another Quenching Medium Suggested

Speith and Lange (page MA 184 R 9) suggest that water solutions of pectin have quenching power analagous to that of oil, though one would not expect such solutions to be very stable. The hardening room may yet be ordering currant jelly and the like among its raw materials.—H.W.G.

### More on Precipitation Hardening of Steel

Researchers don't always agree and the work of Minkevich shows that there is lack of complete harmony among those studying precipitation hardening in low-carbon steels (page MA 186 L 7).—O.E.H.

### Combustion Atmosphere

A contribution to the important and neglected subject of atmosphere in industrial heating furnaces is made by Segeler (page MA 188 L 2). Specific recommendations are made, which is rare in discussions of this elusive subject.—M.H.M.

### Torch Deseaming of Billets

Torch deseaming is an important application of the oxyacetylene cutting process known as "flame machining" which recently has begun to take shape. This process utilizes the same fundamental principle of chemical reaction of oxygen with steel, but differs in that the cutting oxygen stream is made to impinge at a more or less acute angle on the work, in some cases almost tangentially. The cut is not permitted to penetrate through the work, as in severing, but is restricted to removal of a predetermined depth and width of material from the surface by oxidation (page MA 190 R 2).—E.V.D.

### Quality of Galvanizing Related to Microstructure of Steel Base

It is generally admitted that the galvanizing properties of ferrous materials differ considerably among themselves. For example, one has very little difficulty in picking out a sheet of wrought iron from a lot of steel sheets, all of which were galvanized under comparable conditions. According to a recent German investigation, steel sheets may likewise vary considerably among themselves in their galvanizing properties, the difference being attributed to the form and distribution of the carbon-bearing constituent. Superior results are claimed if this constituent exists as carbide at the grain boundaries, rather than as "undivorced" pearlite page MA 195 L 9).—H.S.R.

### For Better Aircraft

The Edgar Marburg Lecture by Tuckerman (page MA 197 L 2) predicts that future improvement in light weight construction for aircraft, railroad cars, etc. will come about principally through improvement in design and fabrication, and not through improvement in materials.—C.S.B.

### That Which We Call a Rose!!!

Some metallographers are not so lenient as Juliet (Act. II, Sc. II) for they have definite ideas on what the various constituents of steel should be called. Styri, for example (page MA 199 R 6) disapproves the use of the term "troostite" except as applied to the dark constituent (after suitable etching) in quenched steel. "Sorbite" is tempered martensite unresolved at 1000 diameters; "fine granular pearlite" is the similar constituent resolved at that magnification. Harder (page 199 R 6) criticizes "spheroidized pearlite" on the ground that the terms are mutually exclusive. Scott (page MA 199 R 7) presents his thoughts on the definition of boundaries between martensite and troostite and between troostite and sorbite. Somewhat different in scope, but worth a place in this collection of names, is the summary of Van Horn (page MA 199 R 7) of information on the nature of the constituents. And finally there is a brief message from the Maestro (page MA 199 R 8).—J.S.M.

### Largest All-Welded Ship

An editor's note in "Metal Progress" on the "Joseph Medill" (page MA 190 R 3) mentions that this ship did not arrive at its destination. No inference should be drawn that welding had anything to do with the loss of this ship. —R.R.

### Sprayed Zinc Coatings Unique for Some Purposes

Advocates of the metal-spraying process as a coating method usually rely upon the well established and more or less conventional supporting arguments that apply to metal coatings in general. An advantage of zinc coatings which is appreciated by comparatively few workers is its usefulness for protective purposes against discoloration of a chemical product as in the manufacture or storage of celulose acetate in steel containers. Very slight rusting of iron would seriously impair the usefulness of the lacquer for purposes for which appearance is of prime importance, e.g., furniture. Zinc compounds are colorless, hence the advantage of coating the container with zinc. The metal-spraying process is admirably adapted to such purposes (page MA 195 L 8).—H.S.R.

# ZINC ALLOY DIE CASTINGS

## STRUCTURAL AS WELL AS ORNAMENTAL

Radiator ornaments have always been ZINC Alloy Die Castings because complicated shapes, ornamental details and smooth, easily finished surfaces are easily produced by this method of fabrication.

Fully appreciating these manufacturing advantages, automotive engineers have always worked in close cooperation with die casters to develop new applications in the design of cars. The improved properties of the new ZINC Alloys gave them added advantages, with the result that ZINC Alloy Die Castings are now being used in structural applications as well as the ornamental and mechanical functions they have filled in the past.

Both the Society of Automotive Engineers and the American Society for Testing Materials have approved ZINC Alloys for Die Casting corresponding to new alloys developed by The New Jersey Zinc Company and based on Horse Head Special ZINC.

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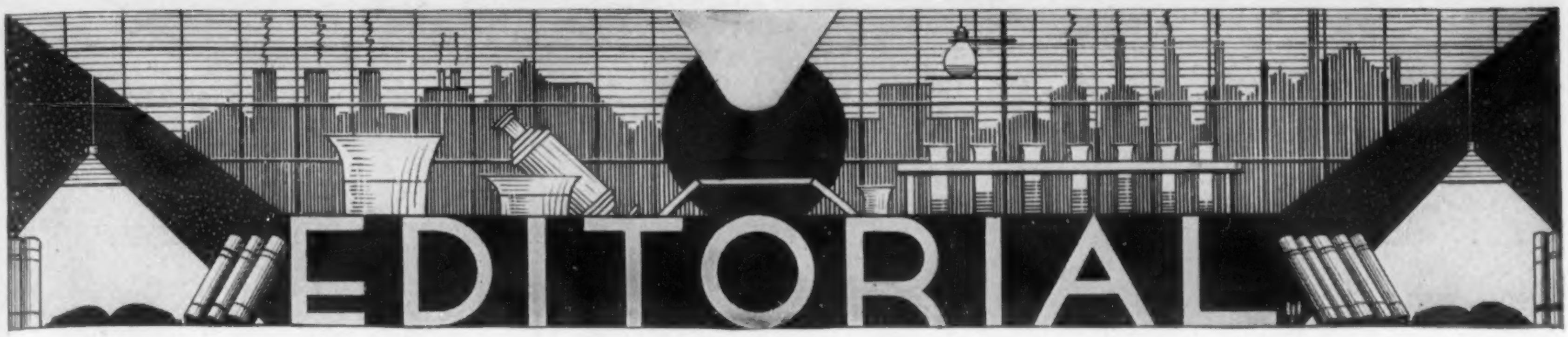



## Angle-Iron Joe

ONE of the most progressive metal-working firms, famed for its ability to get rapidly into quantity production on a new specialty for the automotive trade, has on its staff a self-made development engineer generally known as "Angle-Iron Joe." Joe has ideas, plus a consuming desire to see how they will work out. When he gets an idea, instead of first going into extremely detailed computations, making an elaborate design, getting it traced and blue printed, and built by the machine shop, he grabs some angle iron and various parts out of stock and with the use of a drill press, a few stove bolts, and a little hay-wire, builds him a contraption that will run a little while and show him how the basic idea is going to work.

Based on that experience, one a bit more substantial is constructed and tried out. Pretty soon he has one from which the bugs have been sufficiently eliminated so that a machine-shop made outfit can be built that is much nearer the final production set-up than would have been reached in that time, by the road of more expensive outfits more painstakingly designed.

Many research workers could well take a tip from Angle-Iron Joe. Too often the research man is prone to spend a lot of time putting his vision for special equipment, necessary to the working out of an idea, on the drawing board and through an always-clogged machine shop, and to have to sit around waiting for the equipment, since he can't tell what turn to take till he gets the results of tests with that equipment. Lots of times very crude equipment would be ample to show the correctness or incorrectness of the basic idea, and if it is correct, the jerry-built outfit will usually have shown how a more meticulously constructed one ought to differ from the one its designer first thought of.

People vary greatly in their ability to toggle equipment together themselves, but beyond the question of manual dexterity there is also one of the point of view. In our own organization the workers who get the most done the quickest, and usually the best in the long run, are those who are not too proud to work with relatively crude equipment that they assemble themselves, for qualitative results, even though at a later stage the instrument-maker's precision is required for sufficiently quantitative results. We like to see a little of Angle-Iron Joe even in the men dealing with the most exacting problems.—H. W. G.

## On Re-Reading

ONE is prone to consider that the only worthwhile data are the very recent ones, and that the old-timers' dope may be disregarded without loss. It is assumed that, since science and technology are built upon past knowledge and experience, the latest practice includes all that is worthy of the older knowledge.

This assumption is obviously not correct in politics where the New Deal scoffs at past experience and is accumulating its own, at horrible cost to the country, but nobody looks for logic or consistency among Farleys and Tugwells or the higher-ups who condone their actions. Perhaps we are illogical in taking for granted the correctness of up-todate metallurgical practice and very probably, just as the politician could profit by a study of history, so the metallurgist might profit by study of the previous knowledge that is on record but is not now practiced.

Indeed, some of our best modern metallurgical achievements are but the rejuvenation of older knowledge and its application amid more favorable engineering and economic conditions. One might well browse among the writings of the old timers with an eye to present application of forgotten truths.

We have previously commented (October, 1935, page 280) in regard to modern high yield-strength steels utilizing phosphorus as alloying element, on the phosphorus steels used by John Fritz in 1874 and by Robert W. Hunt in 1885. We note that high-yield steels, almost exactly matching a steel that has recently held the limelight as a new product, were described by Clamer[1] in 1910.

A steel foundryman recently suggested to us a kink in melting practice that might be very much worth while. A day or so later, browsing in John Howe Hall's "The Steel Foundry," published in 1914, we found the same suggestion, almost word for word. As far as we know, nobody has tried it yet, but present economic conditions seem to warrant a trial.

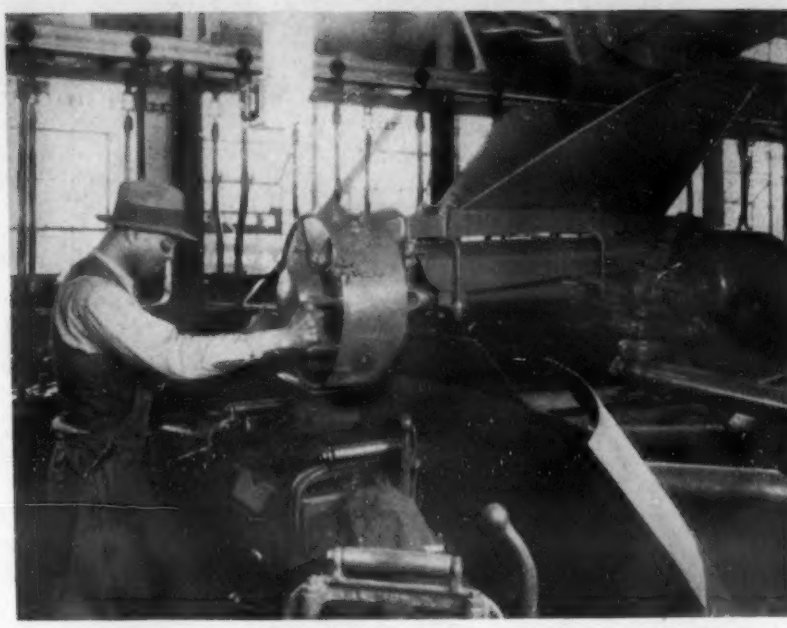
We have been thinking that the Perrin process was very much of an innovation, yet a colleague called our attention the other day to practices described by Lowthian Bell[2] in 1877, and by Holley[3] in 1880, which sound awfully close to the Perrin process.

Doubtless, much more useful data could be dug up from the older literature if one set himself to the task. Just as the old tailings-piles have often proved later

*(Continued on page 94)*

# The Lincoln-Zephyr Cast Alloy Piston

By EDWIN F. CONE



**Molds for the Pistons Being Prepared with a Sand Slinger.**

UNTIL QUITE RECENTLY automobile pistons have been made of either aluminum or cast iron. Of late there has been a tendency to substitute some other metal or alloy for these familiar products. Evidently there have been some very good reasons for these efforts. Some say that, after a few thousand miles, there develops a slapping of the piston and consequent noise, accompanied by high oil consumption. Lack of adequate wear resistance has also been mentioned.

In any event, to overcome these reported disadvantages, to whatever cause they may be due, several attempts have been made to produce a metal for a piston which should have approximately the same expansion as the cylinder block metal—also one with sufficient hardness to withstand wear. A prime object also was to keep the weight down to that of the aluminum piston. These ends, with one exception, could be accomplished by using a high grade alloy cast iron, but the weight, necessary to insure adequate strength, was realized to be a distinct disadvantage.

The Ford Motor Co., realizing these facts, decided to attempt to develop a special alloy piston which should combine all the desirable properties of the older metals, which should at least be equal in weight to the aluminum with a coefficient of expansion less than aluminum, and which should possess the necessary strength and hardness. A metal which is reported to meet these desired properties has been perfected by the Ford metallurgists and is now being used in all Lincoln-Zephyr automobiles. The story of the metallurgical development of this metal, which is termed an "alloy steel," is privileged to be told by METALS AND ALLOYS.

To develop such a metal piston was beset with many problems: It must be a metal which would be capable of casting into a very thin wall, one that could be heat treated to secure the desired physical properties, and one that could be finish machined to a high degree of accuracy. It was realized that an ordinary steel is especially difficult to handle, but it was believed that some modification of such a steel could be successfully developed, especially with the experience in developing the cast metal crank shaft (METALS AND ALLOYS, October, 1935) as a valuable background.

Various analyses were tried for a suitable casting metal—both low and high carbon, low and high silicon, with varied amounts of different alloying elements—all a modification of steel casting metal. As a result of a large number of trials, the following composition was arrived at:

| | *Per Cent* |
|---|---|
| Carbon | 1.35 to 1.70 |
| Manganese | 0.60 to 1.00 |
| Silicon | 0.90 to 1.30 |
| Sulphur | 0.08 max. |
| Phosphorus | 0.10 max. |
| Copper | 2.50 to 3.00 |
| Chromium | 0.15 to 0.20 |

It is pointed out that, commenting on this analysis, the necessary strength could be obtained with a lower content of carbon, silicon and copper, but the casting properties, with these elements or any one of these lower in percentage, would be so inferior that a good casting would not result. Again ideal casting properties could be obtained with a higher carbon or silicon percentage, but it is stated that the physical properties would not be high enough for a light piston. Thus the composition, given above, was selected as the one coming closer to insuring the desired properties—of course, after heat treatment.

The heat treatment of the pistons, made of the composition just discussed, must necessarily be very carefully controlled to eliminate warpage and excessive growth and to insure uniform hardness and the desired physical properties. Here again the selection of the final analysis was to a certain extent determined by the effect of the heat treatment.

A metal with a lower carbon content could be easily heat treated without excessive growth or warpage, but a higher carbon would grow very much as well as non-uniformly. The reason for this careful balancing of the elements, followed by the necessary heat treatment is that a piston of a wall thickness of 0.035 in., which is held within a very close weight limit, would be impossible to produce, unless castings were held to a uniform size, so far as warpage and growth are concerned.

A simple annealing of this composition at 1650 deg. F., soaked for 30 min., and furnace cooled in 2½

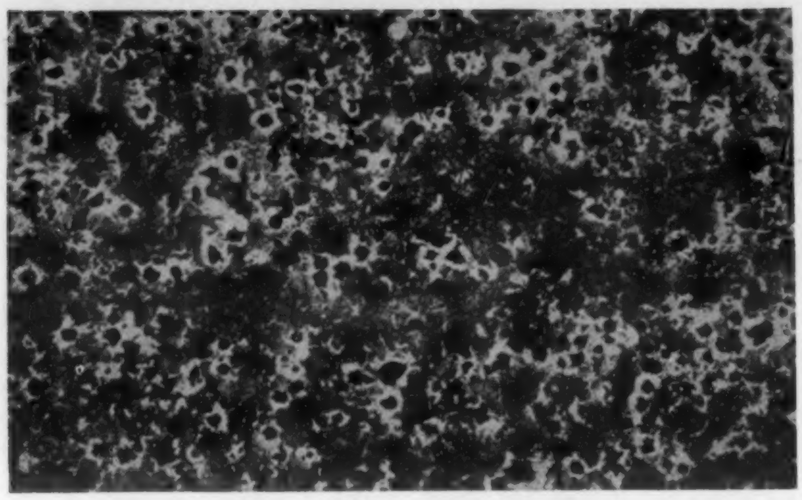
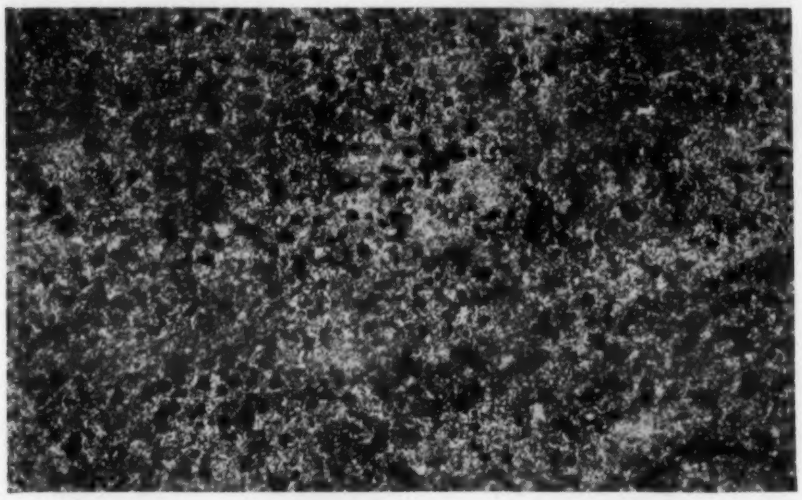


Fig. 1. (Left). Structure of Composition after Simple Annealing—Lamellar Pearlite with Rosettes of Secondary Carbon. Etched in 5 per cent nital. 100 diameters. Fig. 2. Same as Fig. 1, Except at 1,000 Diameters.



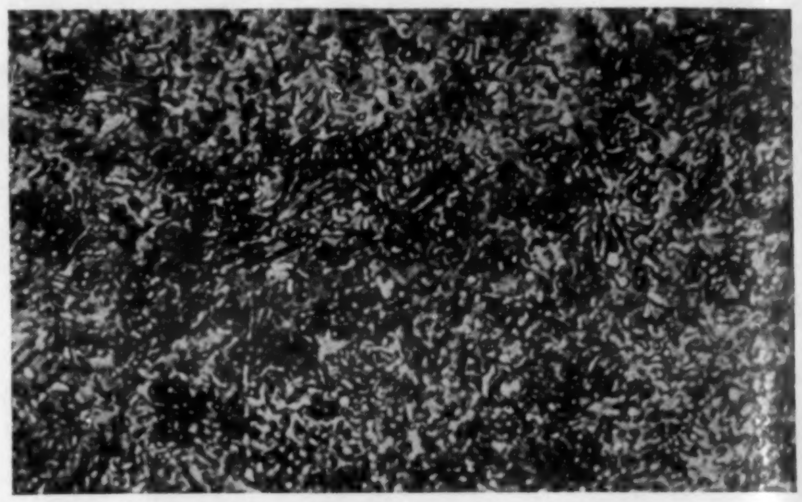
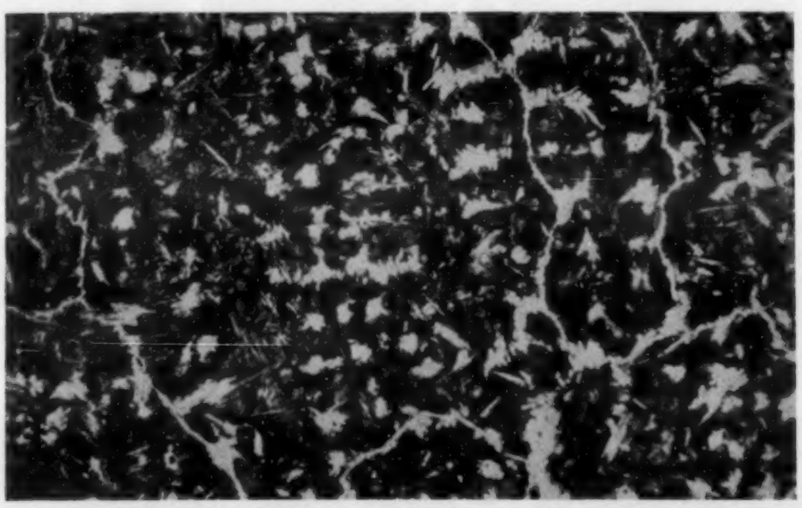


Fig. 3 (Left). Structure of the Same Composition after Special Heat Treatment (See Text). Etched in 5 per cent nital. 100 diameters. Fig. 4. Same as Fig. 3, Except at 1,000 diameters.



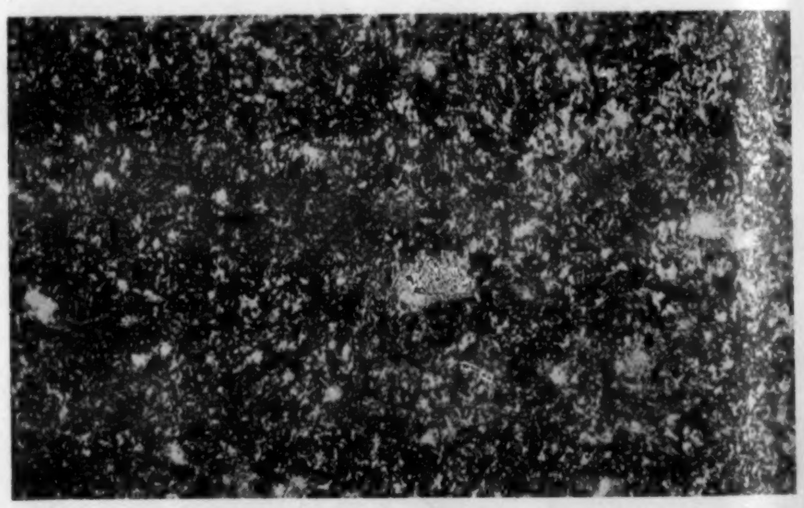
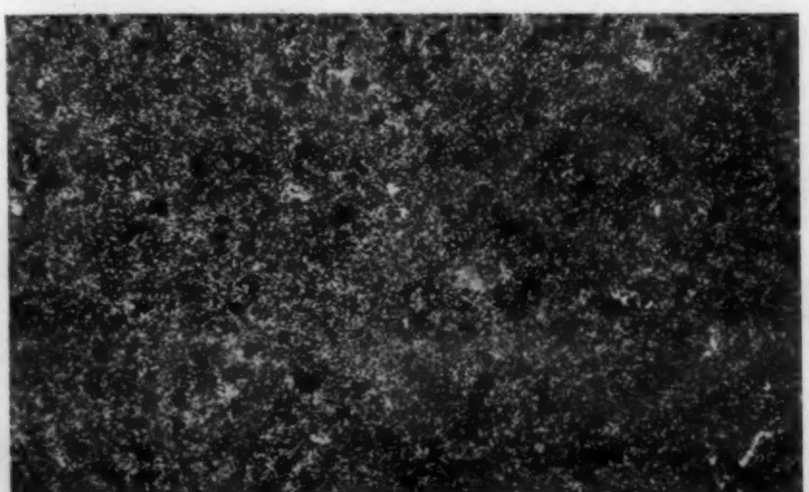


Fig. 5 (Left). Structure of Piston Metal as Cast. Etched in 5 per cent nital. 100 diameters. Fig. 6. Structure of Metal of Fig. 5 after First Treatment. Etched in 5 per cent nital. 100 diameters.



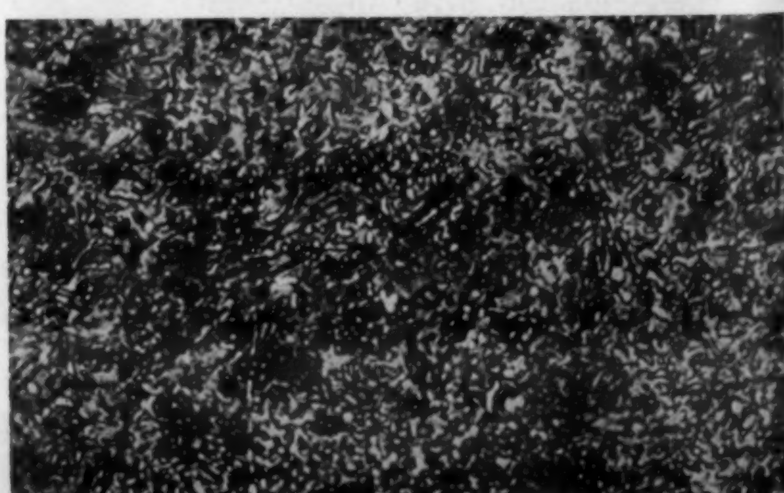
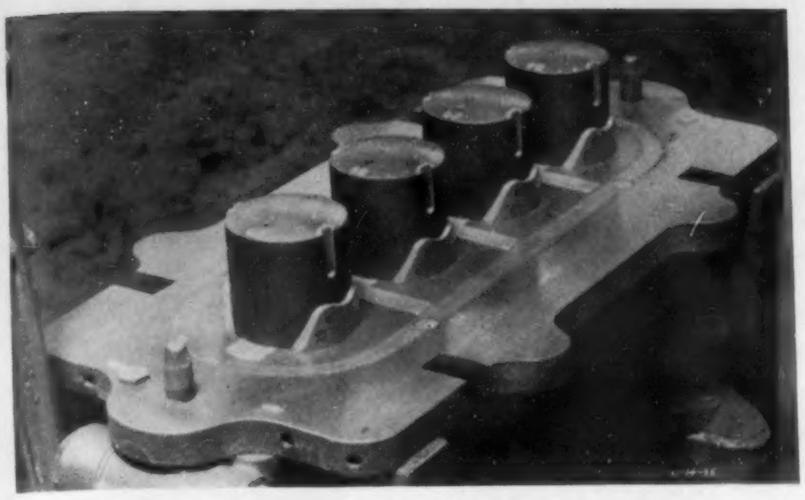


Fig. 7 (Left). Structure of Metal of Fig. 6 after Final Anneal. Etched in a 5 per cent nital. 100 diameters. Fig. 8. Same as Fig 7, Except at 1,000 diameters.



Part of One of the Molds for the Lincoln-Zephyr Pistons.

hrs. to 1200 deg. F. produces a structure of lamellar pearlite with rosettes of secondary carbon. (See photomicrographs Figs. 1 and 2) But for wear purposes in the motor and for machinability, a spheroidized pearlitic structure with secondary graphite, Figs. 3 and 4, is more desirable. This is accomplished by the following heat treatment:

Heat to 1650 deg. F. and soak for 20 min. Air cool to a maximum of 1200 deg. F. Reheat to 1400 deg. F., hold for 1 hr., and furnace cool to 1000 deg. F. in 1 hr.

This treatment produces a Brinell of 207 to 241 and a structure as described above—spheroidized pearlite with secondary graphite. The accompanying photomicrographs, Figs. 5, 6, 7 and 8, reveal the structure at the different steps in the heat treatment cycle just described, and what is accomplished in each step:

Fig. 5. As cast, 100 dia.
Fig. 6. After 1650 deg. air cooled, 100 dia.
Fig. 7. After 1400 deg. draw, 100 dia.
Fig. 8. After 1400 deg. draw, 1000 dia.

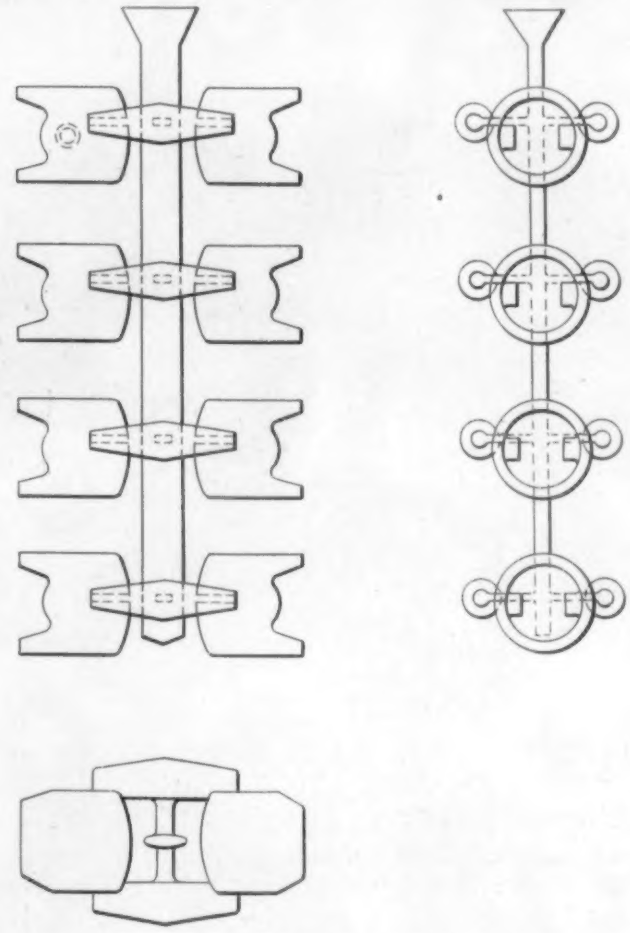
The furnaces used for the heat treating operations are gas-fired, continuous roller rail type.

The physical properties of the metal as it goes into the car are also determined by the analysis and heat treatment. It is considered necessary to have a fairly ductile material, yet one rigid enough. It must also possess some heat conductivity. After considering the casting properties and the response to heat treatment, the physical properties of the analysis selected were found to be satisfactory. The metal in the finished pistons has the following approximate physical properties:

| | |
|---|---|
| Elastic limit, lbs. per sq. in. | 70,000 |
| Tensile strength, lbs. per sq. in. | 90,000 |
| Elongation in 2 in., per cent | 5.0 |
| Brinell | 207 to 241 |

It is pointed out that the small particles of secondary graphite, imbedded in the spheroidized pearlite, furnish excellent wearing qualities against the cylinder wall.

The melting of the alloy steel for these pistons is done in a 4-ton electric arc furnace, so built that charging is accomplished with the roof removed. A typical charge, put in the furnace as cold metal, is as follows in pounds:



Sketch of the Method of Assembling the Eight Pistons in a Mold for Pouring.

| | *Lbs.* |
|---|---|
| Low phosphorus pig iron, 3.50% Si. | 2400 |
| Low carbon steel scrap | 3444 |
| Copper | 180 |
| Back Scrap (Piston sprues and gates) | 2000 |
| Fe Si (50%) | 70 |

The temperature of pouring, which is very carefully regulated, is 2850 to 2900 deg. F.

The molds for the pistons are of green sand with eight pistons to the mold, as shown by the diagram. The molds are made on a turntable with the sand slung into the flasks with a sand slinger, as shown by one of the illustrations. This insures the uniform ramming necessary for control of size. The flasks are then assembled, placed on an endless conveyor and poured. No dry sand cores are used in casting the pistons.

The machining of the pistons, the outside diameter of which is held to a limit of 0.0003 in., is accomplished on a Bullard multimatic machine and on a operation. Here again the analysis and heat treatment had to be considered to insure ease of machining.

Another Portion of One of the Molds for the Lincoln-Zephyr Pistons.

# Alloys of Copper and Iron

By K. M. SIMPSON and R. T. BANISTER

*Consulting Engineer, New York, and Metallurgist, Wilbur B. Driver Co., Newark, N. J., Respectively*

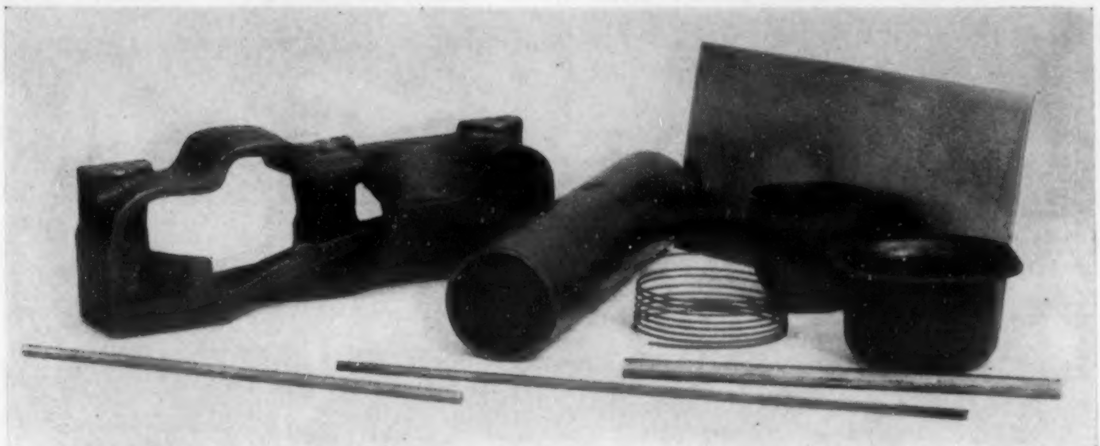


**Fig. 1. Various Products Made of the Copper-Iron Alloys.**

THE ANNOUNCEMENT THAT IRON AND COPPER have been combined to form a complete series of workable alloys has been received by many metallurgists with more or less surprise. This is natural, for it would seem that two metals as old as are these two would have been alloyed long before this, were such a combination possible. The literature records many attempts in this direction, and doubtless there have been numerous other attempts that have never been recorded.

### Historical

Going back to the early efforts, we find that Faraday and Stodart[1] in 1820 published the results of their experiments in the addition to steel of 2 percent of copper which they found contributed no improvement to the steel. Even before this, Rinman[2] in 1783 tried heating a mixture of five parts of iron and one part of copper in the blast furnace, and produced a button of hard and tough metal. But his conclusion typifies that of most of the later investigators. He states: "It cannot be denied that the presence of copper in iron causes incurable red shortness." Mushet[3] in 1835 published the results of his rather extensive experiments in this field. He says, "Pure malleable iron may be united with copper in any proportion until it equals or even exceeds the weight of copper . . ." It must have been the red shortness of the alloys. He says that steel with 5 percent of its weight of copper was useless for forge purposes—that discouraged him from carrying on the development.

It would be impossible to review completely the literature here. Percy in his "Metallurgy of Iron and Steel" reports most of the work done up to 1864, and Stead[4] in his paper covering the structure of alloys of iron and copper, published in 1901, reviews the investigations carried on up to that time. Stead did not investigate the physical properties of the alloys, nor did he study their workability. Breuil[5] in 1907 published his paper which more or less supplements that of Stead in that he describes the results of numerous physical tests and the study of the critical points of the various alloys he considered. These were alloys containing: (a) carbon 0.103 to 0.168 percent and copper 0 to 32 percent; (b) carbon 0.282 to 0.40 percent and copper 0 to 32 percent; and (c) carbon 0.560 to 0.798 percent and copper 0 to 32 percent. He found that only the alloys of series "a" and "b," containing less than 4 percent copper, were capable of being forged.

Burgess and Aston,[6] whose work was completed in 1909, reported regarding the forgeability of the iron-copper alloys as follows: "Alloys up to 2 percent copper forge well at low heats. Those from 2 to 7 percent will not forge at a low heat, and rather poorly at white heat, the ease of workability varying inversely as the percentage of copper. From 7 to 75-80 percent the alloys may be classed as non-forgeable. Between 80 and 100 percent they will forge at a fair red heat but not at a normal forging heat for iron." Since this paper of Burgess and Aston's, little has been written of the alloys of copper and iron with copper exceeding 7 percent.

During the past few years much has been published on the "copper steels," with copper generally less than 2 percent, principally concerning their corrosion re-

Table 1.—Physical Properties at Room Temperature of 50% Copper-50% Iron Alloy

| | Ultimate strength, lbs. per sq.in. | Yield point, lbs. per sq.in. | Elongation in 2 in., per cent | Reduction of area, per cent | Hardness Rockwell B | Hardness Brinell | Modulus of elasticity, lbs. per sq.in. | Impact value, ft. lbs. |
|---|---|---|---|---|---|---|---|---|
| As sand cast | 55,000 | 32,000 | 25 | 42 | .. | 130 | ........ | ............ |
| As sand cast and water quenched from 1625 deg. F (885 deg. C.) | 63,500 | 46,000 | 22 | 35 | .. | 143 | ........ | ............ |
| As sand cast and furnace cooled from 1625 deg. F. | 48,000 | 33,500 | 31 | 60 | .. | 103 | ........ | ............ |
| As forged | 69,000 | 65,000 | 28 | 70 | 80 | 132 | 23,000,000 | Charpy 36-38<br>Izod 71 |
| As forged—Tested at —110 deg. F. | 73,500 | 75,000 | 35 | 61 | .. | ... | ........ | Charpy 36 |
| As forged and water quenched from 1710 deg. F. (930 deg. C.) | 87,500 | 64,000 | 28 | 33 | 88 | 170 | ........ | ............ |
| As forged and furnace cooled from 1710 deg. F. | 58,000 | 48,000 | 42 | 72 | 63 | 107 | ........ | ............ |
| As forged and water quenched from 1625 deg. F. (885 deg. C.) | 72,500 | 63,500 | 24 | 57 | .. | 150 | ........ | ............ |
| As forged and furnace cooled from 1625 deg. F. | 51,000 | 43,000 | 50 | 72 | .. | 108 | ........ | Charpy 36-38 |
| As hot rolled rod—¼-in. dia. | 101,500 | 68,000 | 8 | 65 | 98 | ... | 24,500,000 | ............ |
| Cold rolled sheet—Longitudinal to direction of rolling | 64,000 | ..... | 8 | .. | 80 | ... | ........ | ............ |
| —Transverse to direction of rolling | 77,000 | ..... | 4 | .. | 80 | ... | ........ | ............ |
| Cold drawn wire | 224,000 | ..... | 1.5 | .. | .. | ... | ........ | ............ |

sistance and precipitation hardening characteristics. The constitutional diagram of Ruer and Goerens,[7] published in 1917, indicating a range of two immis-

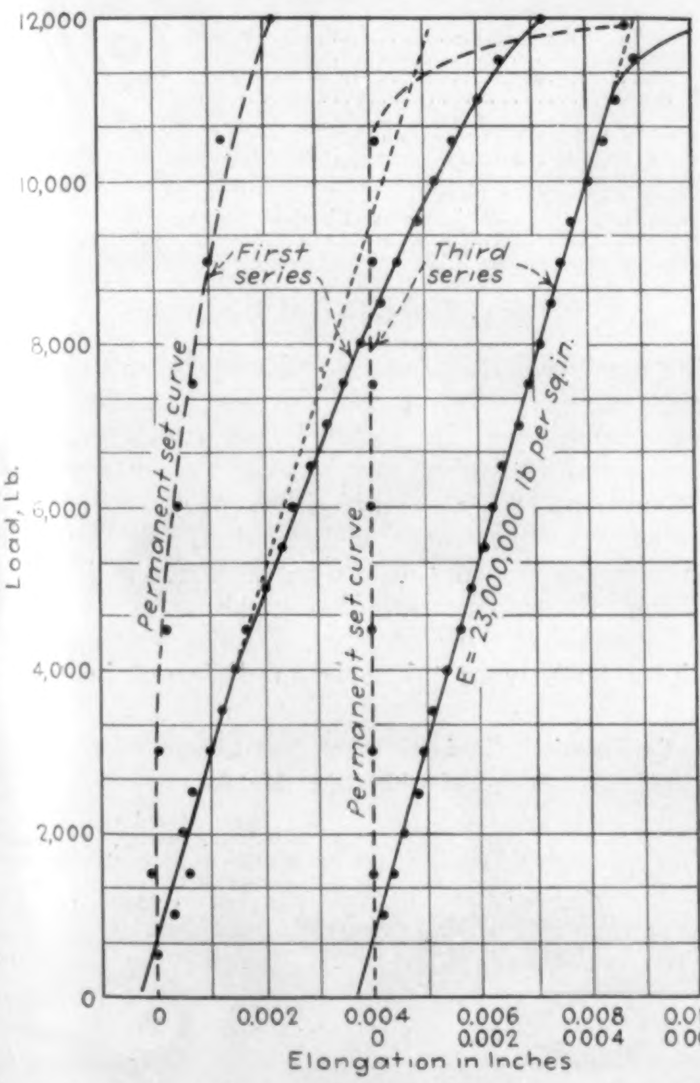



**Fig. 2. Load Elongation and Permanent Set Curves of 50 Cu-50 Fe Alloy. Forged Material.**

cible liquids, has probably discouraged the investigation of the series in the higher ranges of copper. The repeated reference to the unforgeability of copper-iron alloys by previous investigators has probably also contributed to the lack of interest. From our own experience, we know that any first attempts to make the alloys are certain to be most disappointing.

## The 50-50 Alloy

Although our investigation covered alloys ranging from 85 percent copper and 15 percent iron to 15 per-

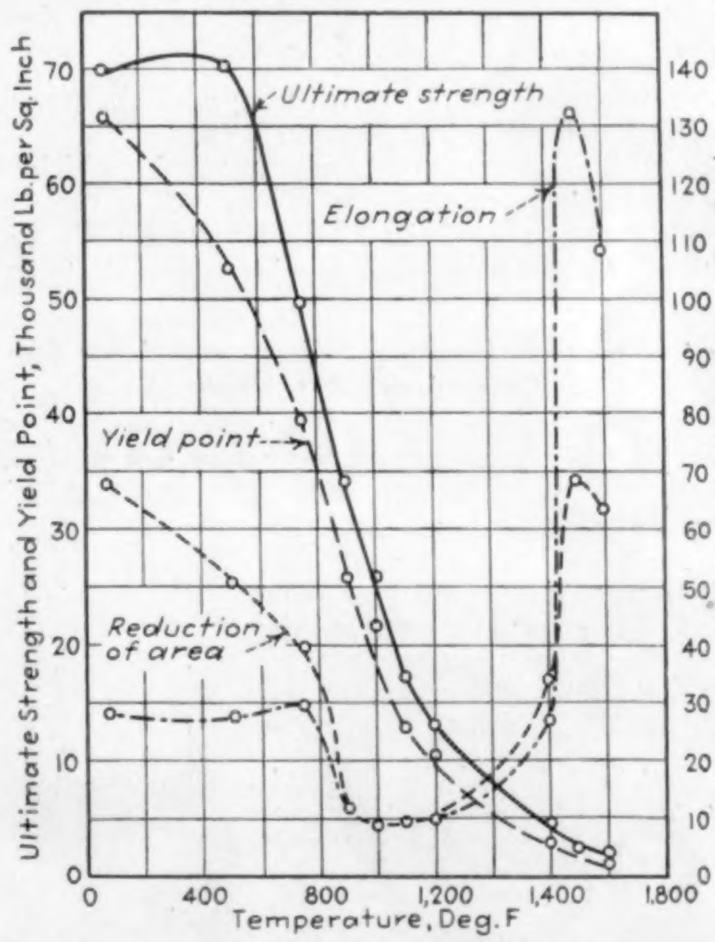



**Fig. 3. Results of Short Time Tensile Tests at Elevated Temperatures of the 50 CU-50 Fe Alloy in the Forged Condition.**

cent copper and 85 percent iron, it seemed desirable to center the work on one proportion of copper and iron. It was necessary to establish the method of working the alloys, forging, hot-rolling, annealing, etc.,

Table 2.—Effect of Addition of Elements on Physical and Electrical Properties

| Approximate Analysis | As Forged Material: Ultimate strength, lbs. per sq. in. | As Forged Material: Yield point, lbs. per sq. in. | As Forged Material: Elongation in 2 in., per cent | As Forged Material: Reduction in area, per cent | Hand Drawn Wire: Ultimate strength, lbs. per sq. in. | Hand Drawn Wire: Electrical resistivity, microhms per cu. cm. |
|---|---|---|---|---|---|---|
| 25% Cu, 0.40% Mn, balance Fe | 73,500 | 73,500 | 22 | 63 | 200,000 | 10.6 |
| 25% Cu, 0.70% Mn, balance Fe | 83,000 | 82,500 | 23 | 62 | 210,000 | 12.9 |
| 25% Cu, 0.40% Mn, 2.5% Ni, balance Fe | 98,000 | 89,000 | 13.5 | 22 | 220,000 | 15.6 |
| 50% Cu, 0.50% Mn, balance Fe | 66,500 | 59,000 | 21 | 46 | 153,000 | 6.6 |
| 50% Cu, 1.0% Mn, balance Fe | 71,500 | 65,000 | 22 | 60 | 172,000 | 9.4 |
| 50% Cu, 0.50% Mn, 1.0% Ni, balance Fe | 102,500 | 70,000 | 8 | 15 | 220,000 | 13.1 |

and it was felt that the methods developed for one combination would be applicable with slight change to the other combinations. Consequently, most of the investigation has been carried out on the 50 percent copper and 50 percent iron alloy. This choice was an arbitrary one, made because it was the middle of the

**Table 3.—Effect of Heat Treatment on Hardness**

| Treatment | Rockwell B | Brinell No. |
|---|---|---|
| Hot Rolled Material to ¼ in. Thickness: | | |
| As hot rolled | 90.7 | 183 |
| Quenched in water from 900 deg. C. (1650 deg. F.) | 84.3 | 146 |
| Quenched in water from 800 deg. C. (1470 deg. F.) | 72.9 | 114 |
| Quenched in water from 700 deg. C. (1290 deg. F.) | 78.2 | 128 |
| Air cooled from 900 deg. C. | 87.2 | 152 |
| Air cooled from 800 deg. C. | 72.9 | 114 |
| Air cooled from 700 deg. C. | 77.2 | 118 |
| Furnace cooled from 900 deg. C. | 59.9 | 85 |
| Furnace cooled from 800 deg. C. | 66.6 | 107 |
| Furnace cooled from 700 deg. C. | 76.2 | 123 |
| Sand Cast Material: | | |
| As sand cast | 91.2 | 170 |
| Furnace cooled from 900 deg. C. | 76.7 | 137 |
| Water quenched from 900 deg. C. | 88.6 | 166 |
| Water quenched from 900 deg. C.—Reheated to 500 deg. C.—Water quenched | 90.7 | 174 |
| Water quenched from 900 deg. C.—Reheated to 500 deg. C.—Furnace cooled | 91.5 | 193 |
| Forged Material—6-in. Ingot to 1¼-in. Bar: | | |
| As forged | 82 | |
| Quenched from 1700 deg. F. (925 deg. C.) | 89 | |
| Quenched from 1700 deg. F.—Drawn ½-hr. at 1200 deg. F. | 86 | |
| Quenched from 1700 deg. F.—Drawn ½-hr. at 1000 deg. F. | 91.5 | |
| Quenched from 1700 deg. F.—Drawn ½-hr. at 800 deg. F. | 92.5 | |

series. It might be remarked that the other alloys of the series responded to hot working with the possible exception of those below 20 percent copper.

Fig. 1 illustrates the various forms in which we have been able to produce the alloys. All of the samples illustrated are of the 50 Fe-50 percent Cu combination. As can be seen, it has been possible to pro-

**Table 4.—Thermal Conductivity of 50% Copper-50% Iron Alloy as Compared with Other Metals**

| | Temperature Range, deg. C. | Coefficient Gram Calories per sec./sq. cm. per cm./deg. C. |
|---|---|---|
| 50% Cu-50% Fe alloy, forged | 94 | 0.292 |
| | 205 | 0.299 |
| | 315 | 0.309 |
| Aluminum, pure (99.48%), sand cast [1] | 100 | 0.50 |
| Aluminum alloys:[1] | | |
| (S.A.E. #30; #12 alloy) Cu 7.91, Fe 0.82 Chill cast | 100 | 0.35 |
| | 300 | 0.38 |
| Cu 8.0, Mn 0.98, Chill cast | 100 | 0.25 |
| | 300 | 0.30 |
| Same, chill cast and annealed at 450 deg. C. | 100 | 0.36 |
| | 300 | 0.39 |
| (Y Alloy) Cu 4, Ni 2, Mg 1.5—Sand cast. | 100 | 0.35 |
| | 300 | 0.37 |
| (S.A.E. #34; Lynite) Cu 10, Fe 1.2, Mg 0.25 —Sand cast | 60–300 | 0.34 |
| Brass, yellow [2] | 0 | 0.204 |
| Brass, red [2] | 0 | 0.246 |
| Copper** | 18 | 0.918 |
| | 100–197 | 1.043 |
| | 100–370 | 0.931 |
| | 100–541 | 0.902 |
| Iron, pure [2] | 18 | 0.161 |
| | 100 | 0.151 |
| Steel, 1 per cent C.[2] | 18 | 0.108 |
| Cast iron, as cast [2] | 100 | 0.102 |
| | 300 | 0.099 |
| Monel metal [3] | 0–100 | 0.06 |

[1] Values taken from "The Aluminum Industry"—Edwards, Frary and Jeffries.
[2] Values taken from Smithsonian Physical Tables.
[3] Values taken from National Metals Handbook, 1933 Edition.

duce sheet, wire, hot-rolled and cold-rolled rod, seamless tubing and castings. The sheet shows good deep drawing characteristics, and two small cups drawn from it are illustrated. The casting shown is a section from a cylinder head for an automobile motor and indicates the intricate type of casting possible with the alloy. Seamless tubes, 18 ft. long and 2 ins. in diameter, were produced.

**Table 5.—Thermal Expansion of 50% Copper-50% Iron Alloys as Compared with Other Metals**

| | Temperature Range, deg. C. | Coefficient cm./cm./1 deg. C. $\times 10^{-4}$ |
|---|---|---|
| 50% Cu-50% Fe alloy, forged [1] | 20–100 | 0.185 |
| | 20–400 | 0.165 |
| | 20–600 | 0.167 |
| | 20–800 | 0.163 |
| | 20–900 | 0.150 |
| Copper [1] | 20–100 | 0.192 |
| | 20–200 | 0.185 |
| | 20–400 | 0.184 |
| | 20–700 | 0.194 |
| | 20–900 | 0.201 |
| Cast iron [1] | 20–100 | 0.135 |
| | 20–200 | 0.136 |
| | 20–400 | 0.141 |
| | 20–700 | 0.212 |
| | 20–900 | 0.225 |
| Commercial aluminum sheet [2] | 20–100 | 0.239 |
| | 20–200 | 0.259 |
| | 20–300 | 0.267 |
| Aluminum-copper alloys, Sand cast,[2] Al 87-95 per cent | 20–100 | 0.222–0.246 |
| | 20–300 | 0.264–0.292 |
| Aluminum-manganese and aluminum-manganese-copper alloys,[2] Al 96-98 per cent | 20–100 | 0.231–0.238 |
| | 20–300 | 0.255–0.269 |
| Aluminum-silicon-copper and aluminum-silicon-copper-manganese alloys,[2] Al 84-94 per cent | 20–100 | 0.204–0.234 |
| | 20–300 | 0.221–0.244 |
| Brass [3]-Cu 71, Zn 29 per cent | 0–100 | 0.1906 |
| Bronze [3]-Cu 86.3, Sn 9.7, Zn 4 per cent | 40 | 0.178 |
| Copper [3] | 40 | 0.168 |
| Iron, soft [3] | 40 | 0.121 |
| Cast iron [3] | 40 | 0.106 |
| Steel [3] | 40 | 0.132 |
| Monel metal [4] | 25–300 | 0.14 |

[1] Values determined experimentally.
[2] Values from "Thermal Expansion of Aluminum and Various Important Aluminum Alloys," Peter Hidnert, Bureau of Standards Scientific Paper No. 497.
[3] Values taken from Smithsonian Physical Tables.
[4] Values taken from National Metals Handbook, 1933 Edition.

## Physical Properties of the Alloys

The accompanying tables and curves will show the values that have been found for the physical properties of the alloys. In Table 1 are given tensile and hardness values and a few impact values for the 50 Cu-50 percent Fe material in different conditions. The effect of heat treatment is indicated, but the values given for forged material quenched from 1625 and 1710 deg. F. are not intended to show effect of different quenching temperatures. As the test specimens for these tests were taken from different heats, and

**Table 6.—Electrical Conductivity of Iron-Copper Alloys as Compared with Other Metals**

| | Resistivity, microhms per cu. cm. | Conductivity, per cent that of copper | Ultimate strength, lbs. per sq. in. |
|---|---|---|---|
| 75% copper-25% iron alloy, cold drawn wire (97.4% red. after annlg.) | ... | 25.4 | 137,000 |
| Same, aged at 250 deg. C. | ... | 29.0 | 136,000 |
| 62.5% copper-37.5% iron alloy, cold drawn wire (97.4% red. after annlg.) | ... | 18.6 | 152,500 |
| Same, aged at 250 deg. C. | ... | 24.1 | 152,000 |
| 50% copper-50% iron alloy, | | | |
| Cold drawn wire annealed at 600 deg. C. | 6.26 | 25.4 | 93,000 |
| Cold drawn wire annealed at 820 deg. C. | 6.7 | 23.7 | ...... |
| Cold drawn wire annealed at 990 deg. C. | 6.73 | 23.6 | 65,000 |
| Cold drawn wire, 77% red. after annlg. | 7.13 | 22.2 | 103,000 |
| Cold drawn wire, 93% red. after annlg. | 7.24 | 21.9 | 132,000 |
| Cold drawn wire, 98% red. after annlg. | 7.41 | 21.5 | 204,000 |
| Same, aged at 350 deg. C. | 6.97 | 22.8 | 181,000 |
| Same, aged at 500 deg. C. | 6.18 | 25.7 | 141,000 |
| Same, aged at 650 deg. C. | 6.54 | 24.3 | 90,500 |
| Aluminum wire—hard drawn [1] | 2.8 | 56.8 | ...... |
| Duralumin wire [1]—Cu 3.5-4.5, Mg 0.5-1.0, Mn 0.5-1.0 | 3.35 | 47.4 | ...... |
| Aluminum bronze [2]—Cu 97, Al 3 | 8.85 | 17.9 | ...... |
| Brass [2]—Cu 90.9, Zn 9.1 | 3.64 | 43.7 | ...... |
| Brass [2]—Cu 65.8, Zn 34.2 | 6.29 | 25.2 | ...... |
| Bronze [2]—Cu 88, Sn 12, P 0.94 | 17.8 | 8.8 | ...... |
| Copper [2]—annealed standard wire | 1.587 | 100.0 | ...... |
| Copper-iron [2]—0.4% Fe | 4.08 | 39.0 | ...... |
| Phosphor bronze [2] | 7.75 | 20.5 | ...... |
| Iron [2]—very pure | 8.85 | 17.9 | ...... |
| Iron [2]—soft steel | 11.8 | 13.4 | ...... |
| Iron [2]—hard steel | 45.6 | 3.3 | ...... |
| Monel metal [3] | 42.5 | 3.8 | ...... |

[1] Values taken from "Metallurgy of Aluminum and Aluminum Alloys," R. J. Anderson.
[2] Values taken from "American Handbook for Electrical Engineers," H. Pender.
[3] Values taken from "National Metals Handbook," 1933 Edition.

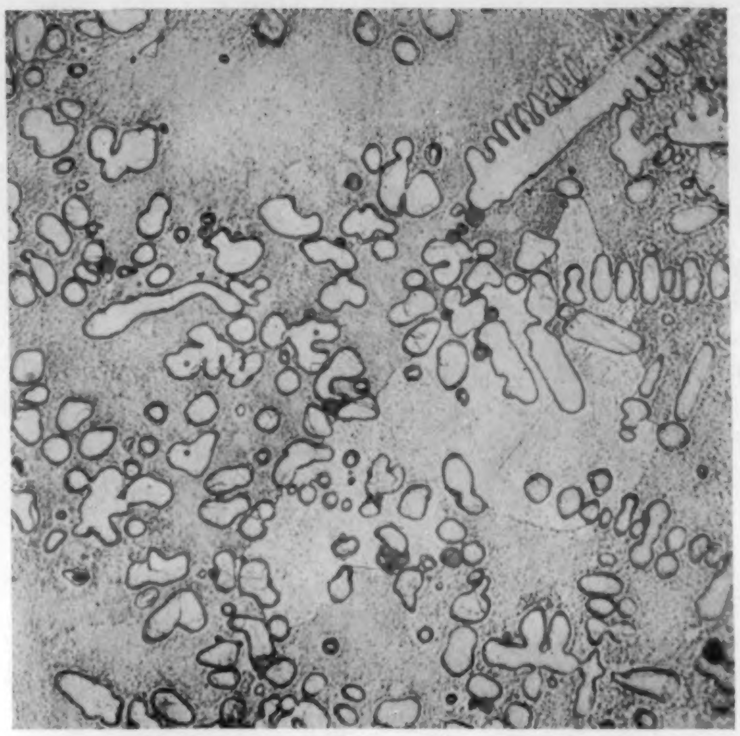


Fig. 4. 75 Cu-25 Fe: As Cast. Etched with Picric Acid and $NH_4OH + H_2O_2$. 250 diameters.

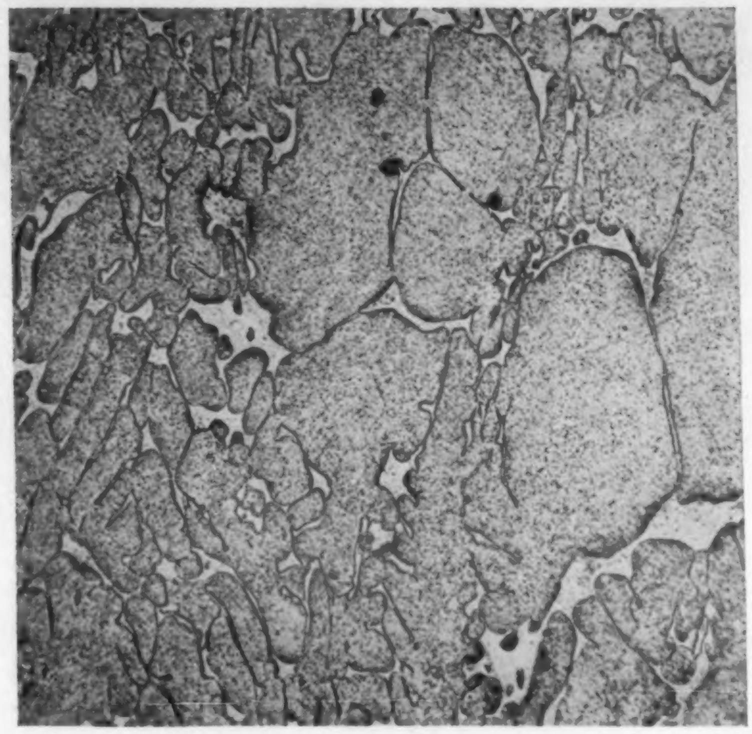


Fig. 5. 25 Cu-75 Fe: As Forged (slightly). Etched with Picric Acid and $NH_4OH + H_2O_2$. 250 diamters.

the tests were made in different laboratories, no conclusions should be drawn. It seems more logical to credit the variations to differences in analysis or to amount of reduction undergone, rather than to the difference in quenching temperature.

Table 2 illustrates the changes produced in the properties by additions of other elements. The extent to which the tensile values depend on the amount of reduction the material has undergone either from hot or cold work is to be noted from the data of Table 1. Further data are given in Table 3 on the effect of heat treatment on hardness. There apparently is some slight tendency towards precipitation hardening but the effect is small. The relatively high yield point, particularly of the 25 percent copper alloy, is to be noted. Although the yield point is generally found to be high and is well marked, the proportional limit in the non-work-hardened material is low as shown in the first load-elongation curve and permanent set curve of Fig. 2. Such curves are of the type characteristic of non-ferrous materials. In Fig. 2 there is also included a load-elongation curve and permanent set curve obtained on the same specimen after it had been twice stressed to its yield point and the load released. By thus stressing, the yield point and proportional limit had been raised and the ratio of load to elongation was constant to greater loads. The ratio was the same over the straight section of both curves but greater accuracy in measuring the ratio for calculating Young's Modulus was possible from the third series of curves.

In Fig. 3 are plotted the results of short time tensile tests at elevated temperatures on the 50 Cu-50 percent Fe alloy in the forged condition. The material being produced at the time these tests were carried out offered some difficulties in forging in that the working temperature range was extremely narrow. The curves for elongation and reduction in area indicate the extent of this range. By later improvements in melting procedure, material was produced

Fig. 6. Same as Fig. 5. 3500 diameters.

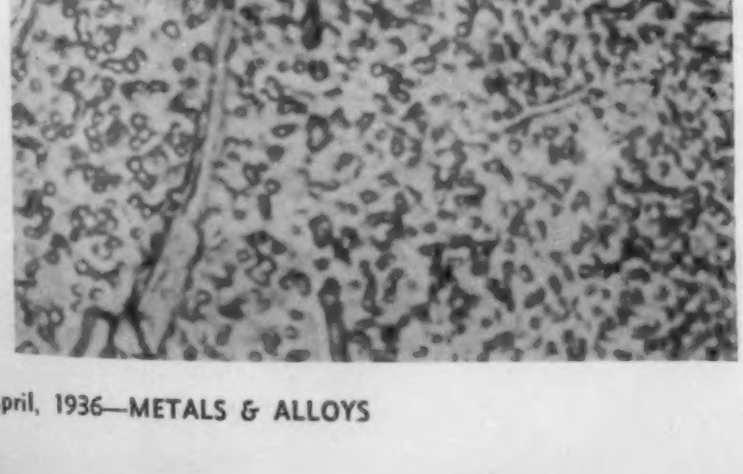


Fig. 7. 50 Cu-50 Fe: As Cast. Etched with $NH_4OH + H_2O_2$. 200 diameters.

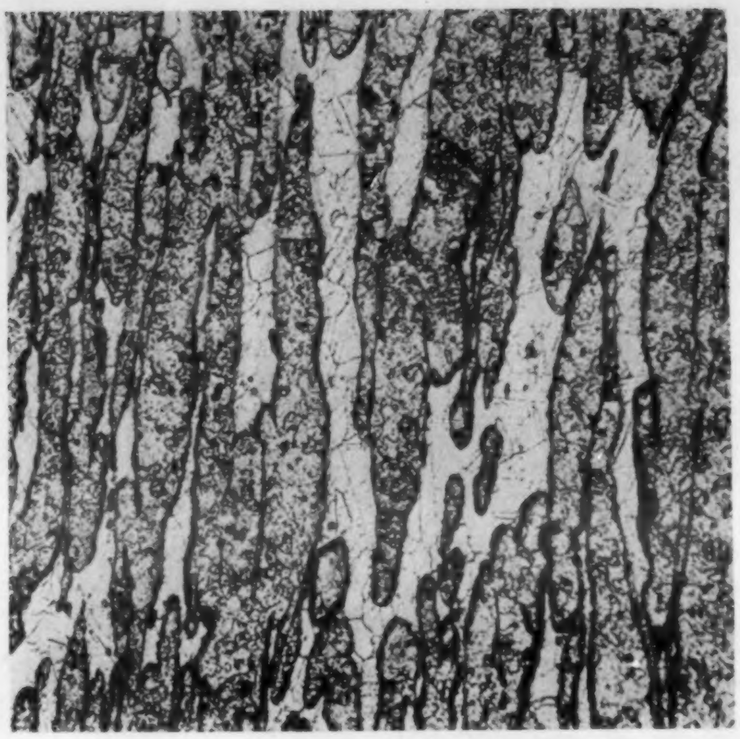


Fig. 8. 50 Cu-50 Fe: As Forged. Etched with 1 Per Cent Nital and $NH_4OH + H_2O_2$. 200 diameters.

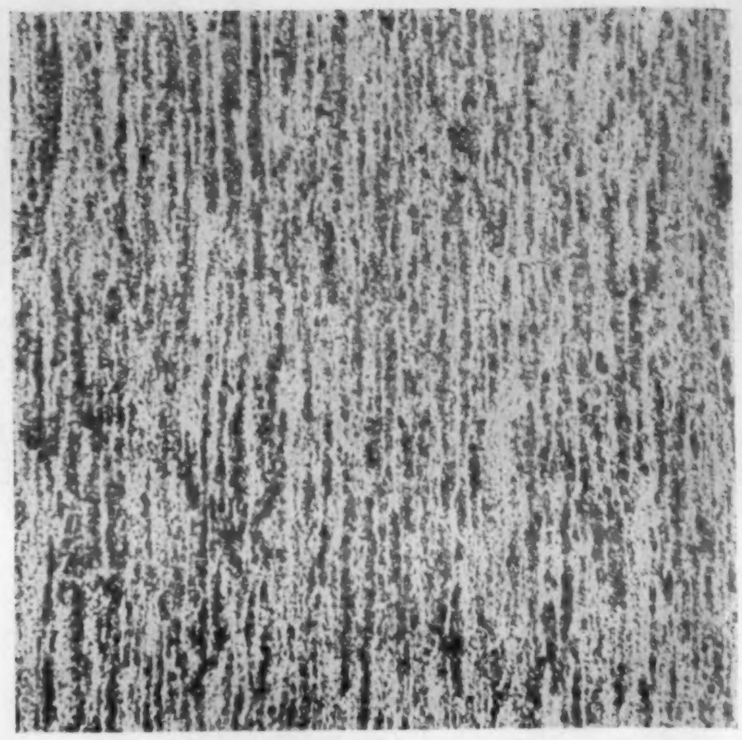


Fig. 9. 50 Cu-50 Fe: As Hot Rolled. Etched with 1 Per Cent Nital and $NH_4OH + H_2O_2$. 200 diameters.

that could be hot worked without trouble down to a temperature at which the material had lost practically all color. Unfortunately no tests at elevated temperatures were carried out on this material and the values shown are the only ones available although they are certainly not representative.

Table 4, showing the thermal conductivity of the 50 Cu-50 percent Fe alloy in comparison with a number of other metals, requires no discussion. The relatively high values shown for this property by the copper-iron alloy give it particular interest for certain uses. In Table 5 is shown the thermal expansion of the alloy and also of copper and cast iron as determined with the same apparatus. Values given for the latter two metals in the Smithsonian physical tables are somewhat lower than those determined experimentally, which indicates there may have been some small constant error in the apparatus used in our determination for which no correction was made.

The electrical conductivity values shown in Table 6 require no explanation.

## Microstructure of the Alloys

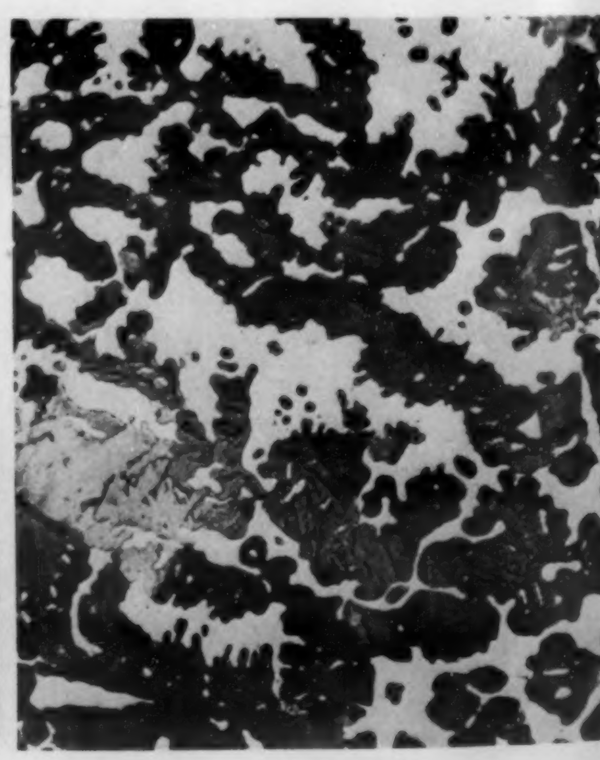
The microstructure of the series of iron-copper alloys is relatively simple although there are a few interesting points to be noted. Except at the extreme ends of the series the alloys are made up of two constituents: A solid solution of copper in iron, Alpha, and a solid solution of iron in copper, Epsilon. The limits of solubility of these two solutions have been studied by other investigators, but we have made no attempt to investigate this phase. The relative amounts of the two solutions present, of course, are proportional to the relative amounts of iron and copper.

In Figs. 4 and 5 are shown the typical cast structures of two alloys, 75 Cu-25 percent Fe, and 25 Cu-75 percent Fe, respectively. The material of Fig. 5 has been subjected to a slight amount of hot work but insufficient to destroy the cast structure. The Alpha solution exists as dendrites in a matrix of Epsilon. It is interesting that ordinarily in the metal as cast, the Alpha solution appears to be a single constituent,

Fig. 10. 50 Cu-50 Fe, 0.15 Per Cent C. Etched with 1 Per Cent Nital. Natural size.

Fig. 11. Same as Fig. 10. 200 diameters.

Fig. 12. 50 Cu-50 Fe, 0.08 Per Cent C: As Cast. Etched with 1 Per Cent Nital. 200 diameters.



yet when the metal is heated for forging or heat treating, an additional finely divided constituent dispersed evenly throughout the iron-rich areas, appears. Presumably this is the copper-rich solution which was soluble in the iron at solidification and held in a supersaturated condition on cooling. On reheating, however, it was precipitated. It will be noted that in Fig. 4 there is no evidence of this constituent, and in Fig. 5, where the metal had been heated for forging, it is clearly seen. Fig. 6 is of the same material as shown in Fig. 5 but at a magnification of 3500 dia. The precipitated constituent is still rather fine for positive identification. Similarly in the copper-rich solution

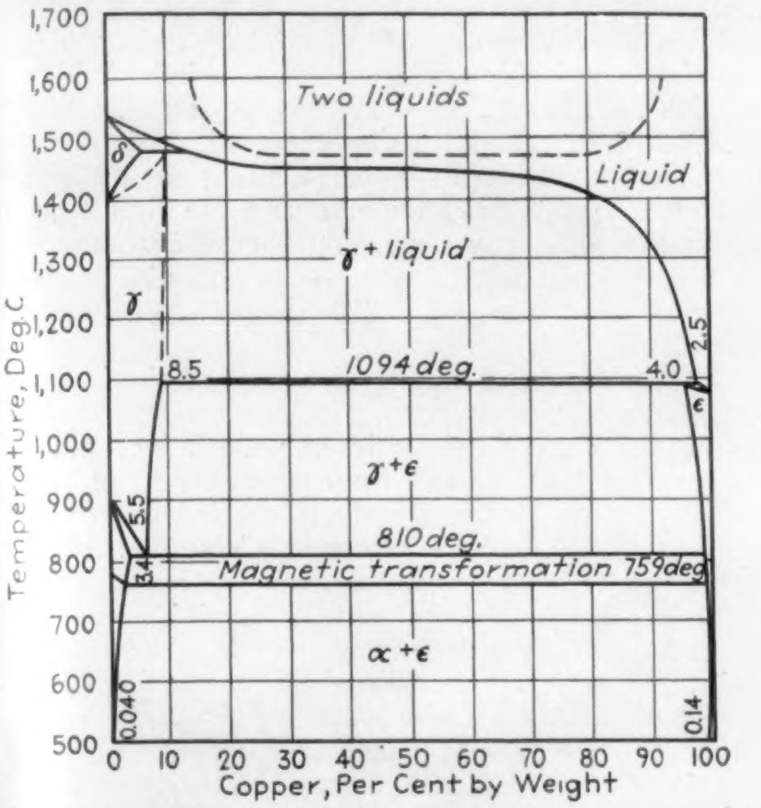



Fig. 13. **Iron-Copper Equilibrium Diagram. Gregg and Daniloff.**

there is generally found an additional constituent which is considered to be the iron held in solution at the higher temperatures after solidification but precipitated as lower temperatures are reached. This constituent is found in the cast as well as in the reheated metal.

Fig. 7 shows the normal cast structure found in the 50 Cu-50 percent Fe alloy. The specimen in this case was etched only with $NH_4OH+H_2O_2$ so that only the copper-rich solution is attacked. Figs. 8 and 9 are also of the 50 Fe-50 percent Cu alloy, and illustrate respectively the forged and hot rolled structures. The twinned crystals characteristic of the copper-rich solution aid in its identification in the photomicrographs, although under the microscope its pink color eliminates any possibility of confusion. The extremely fine fibrous structure shown in Fig. 9 helps explain the properties found in the alloy. The continuous network of the copper-rich solution accounts for the good electrical and thermal conductivity, and the reinforcement furnished by the iron-rich solution produces the high strength.

## Effect of Carbon

Early in our experimental work it was found that carbon exerted a very marked influence on the alloys. With only relatively small amounts of carbon present it was impossible to obtain a homogeneous alloy. Fig. 10 is a photograph at natural size of a cross section of a small laboratory ingot of the 50 Cu-50 percent Fe alloy containing only about 0.15 percent carbon, and shows the separation of the two solutions. Fig. 11 is a photomicrograph at the boundary of the two solutions of the sample shown in Fig. 10. In Fig. 12 is shown the structure of a 50 Cu-50 percent Fe alloy containing 0.08 percent carbon. The dark constituent is the iron-rich solution and in it the iron carbide is plainly evident. The general structure is entirely different from the normal one, and although the alloy appeared homogeneous, it was apparently on the borderline separating a homogeneous material from a segregated one.

The recently published constitutional diagram of Gregg and Daniloff[8] (Fig. 13), which is a composite diagram built up from all available information in the literature, sheds light on the effect carbon exerts. An unusual feature of this diagram is the solubility loop in the liquid area. It is the theory that, within the area bounded by this loop, there will be two immiscible liquid solutions but at temperatures just below those marked out by the loop there is a single liquid solution. The position of this loop is not fixed definitely by the diagram, but it is considered that it is varied by the presence of other elements.

It is possible to lower the loop until it crosses the liquidus line, in which case there is no temperature at which there would not be two liquids for compositions at the central portion of the diagram. Such a lowering of the loop would be produced by the presence of any element which is soluble in one of the liquids but not in the other. In our experience we found no evidence that by super-heating we met with a condition of two immiscible liquids. However, the results shown in Fig. 10 do indicate that carbon produced a condition of two immiscible liquids for which the diagram and the theory of a shifting loop offer a satisfactory explanation. Apparently only 0.15 percent carbon lowered the loop so that it crossed the liquidus line. We found that chromium produced a similar effect, although in this case 2.5 percent of the element was necessary to get such a segregation as is shown in Fig. 10.

A study of the microstructure of the alloys indicates that the corrosion resistance will not be high. Submersion tests in New York City tap water were used to show whether or not the material would rust. The degree of rusting varied considerably from sample to sample, and it soon became evident that carbon exerted a strong influence in this respect also. It appears that the presence of carbon in the iron constituent reduces the amount of copper that may be held in solution, and consequently reduces the resistance to corrosion of this constituent. It is from this iron-rich material that rust is formed. Additions of nickel, or nickel with small amounts of chromium, aided very materially the rust resistance, so that it was a matter of weeks before rust appeared. Eventually there was always some rusting, although in some cases it was very slight. Despite the fact that the alloys do not have corrosion resistant properties, they are in this respect superior to ordinary carbon steel.

## Melting of the Alloys

Regarding the melting of the alloys, the most important factor found was contamination by oxides. Where oxides are eliminated as far as possible, there is no difficulty with regard to forgeability. Though precautions in this respect might seem unnecessary, our experience showed that the alloys are peculiarly

sensitive to such contamination. During the course of our work melting was carried out in a 35 k. v. a. high frequency induction furnace, in commercial size furnaces of the same type in heats of 500 lbs., and in a small open-hearth furnace of one-ton capacity, with success. Obviously the practice followed differed with the type of furnace used. It was our general procedure to make an addition of 0.5 percent manganese after the copper and iron were melted, and then just before pouring further deoxidize with silicon to the extent of about 0.3 percent. The use of a protective slag is advisable.

One interesting and important characteristic of these alloys is the large shrinkage that occurs on solidification. For that reason it is necessary to provide sufficient hot top volume or shrink heads to feed the ingot or casting. In this respect the alloys resemble monel metal, and the precautions taken with this metal are equally required with the iron-copper alloys.

The effect of improper feeding a casting or ingot of these alloys is worthy of mention. If a transverse fracture through the head of an ingot just below the shrinkage cavity is obtained, it will show a gray core surrounded by the normal pink colored metal. If the ingot has been fed properly, this core will extend only a short way and will be limited entirely to the head. In the ingot itself a fracture will show a uniform pink colored material. Analyses of samples taken from the gray core and the surrounding normal material from the head of a 15-lb. ingot have shown: Cu 32.45, Fe 67.20 percent, and Cu 48.70, and Fe 51.15 percent respectively. This segregation is obviously related to pipe, although a sawed section appears to the naked eye sound and homogeneous. This gray core must be the last metal to solidify, and the puzzling question is why it should show a high iron content. It would be expected that the last metal to freeze would be high in copper. We are unable to offer an explanation for the effect.

If the ingot has not been provided with a proper shrink head or if the design of the mold is such that the metal solidifies from the sides towards the center rather than from the bottom towards the top, this segregated core may extend practically to the bottom of the ingot. This segregation effect along the longitudinal axis is readily observed in the iron-copper alloys, but it seems probable that it is common to all ingots. We have never been able to produce good ingots of these alloys in molds which were long in proportion to their cross sectional area. This is not a new consideration but seems to us an extremely important one for mold design for casting any metal. It is often convenient to cast a long ingot of small cross sectional area in order to minimize the reduction necessary to secure the metal in the desired form. All iron-copper ingots which have been made without following rigidly the casting practice outlined above, will show segregation.

It should be understood that the segregation of an improperly fed ingot is quite different from the effect found when through the introduction of such an element as carbon or chromium, a condition of two immiscible liquids results. In the latter case, the gray iron-rich solution is found at the outside and the copper-rich solution at the center of the ingot, which is the type of segregation to be expected. It is probable that many investigators experimenting with alloys of iron and copper have encountered the first type of segregation but have given the explanation for it which should be applied only to the second type. Consequently they have been discouraged from carrying their work farther.

The discussion of our development of the iron-copper alloys cannot be closed without acknowledging the facilities provided us in our work by Columbia University. Most of the work was carried on in the laboratories of Dr. E. F. Kern, professor of metallurgy in the School of Mines at Columbia. His cooperation has been greatly appreciated, and the privilege of using his laboratories was of immeasurable assistance. Although the university has had no interest in the development, aside from permitting it to be carried on in the university laboratories, the various members of the faculty consulted have been extremely kind in their friendly assistance and generosity in granting us the use of various apparatus. We take this opportunity of expressing our appreciation.

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# EDITORIAL COMMENT

*(Continued from page A19)*

bonanzas, so the discarded and neglected information of the past might well be looked up and utilized.—H. W. G.

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## How Steel Export Data May Mislead

THAT statistics, unless carefully analyzed, may be misleading is demonstrated by the data for our export trade in iron and steel. That a revival in this important commerce has taken place has been emphasized in some quarters because total exports of iron and steel of all kinds for 1935 were 3,067,336 gross tons as against 2,832,413 tons for 1934—according to Government data. This is an increase of nearly 8.5 per cent for 1935. But last year the sales of scrap iron and steel abroad expanded to record proportions—2,107,814 tons. They were only 1,835,554 tons in 1934—an increase of over 15 per cent for 1935. The scrap exports in 1934 were a record up to that time.

The real measure of an expansion in foreign demand for iron and steel products is the total sales of other products than scrap. If the scrap exports are deducted from the totals, the exports of American iron and steel products, including pig iron, ferroalloys and castings, were only 959,522 tons in 1935 as compared with 996,859 tons in 1934. While the decrease in 1935 is small, it is nevertheless not an expansion. Exports are at a standstill.

Thus, disregarding scrap, an apparent increase in totals of nearly 8.5 per cent is reduced to a net decline if the data are critically analyzed.—E. F. C.

# Some Alloys of Copper and Iron

## The Tensile, Electrical and Corrosion Properties

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ALLOYS OF COPPER AND IRON have been known for over a century and during this period researches concerning them have been fairly continuous. Since a complete critical discussion of these alloys by Gregg and Daniloff[1] has been published recently as an Alloys of Iron Research Monograph, only a brief review is given here of the early work.

### Historical

Prior to 1900, there was a general disagreement between investigators concerning the effect of copper in iron and steel, and a study by Stead[2] was undertaken in an attempt to settle the controversy. Stead's work with fairly pure copper and iron showed that these elements alloy in every proportion by direct fusion and that there is no tendency for separation into two conjugate liquid layers. Later studies by Pfeiffer[3] yielded data which were not consistent with these observations but which led to the conclusion that no true solubility of copper in iron or iron-carbon alloys existed; the copper was said to be present in suspension in the molten state and as mechanical enclosures in the solid metal. Following the work of Sahmen[4] who advanced the first diagram for the system and found that copper and iron were completely miscible in the liquid state and that there was solid solution of each element in the other amounting to several per cent, Ruer and Fick[5], and later Ruer and Goerens[6], conducted new investigations. In this later work, it was shown that a region of immiscibility could exist in the liquidus but it was not until after Ostermann[7], Müller[8], and Benedicks[9] had studied the system that an immiscibility loop closed approximately 20 deg C. above the liquidus was considered the most probable form of the equilibrium diagram.

Although the effects of copper in iron are now fairly well established, there is still some doubt as to the correct form of the equilibrium diagram. The composite diagram shown in Fig. 1 was advanced by Gregg and Daniloff[1] and was drawn after a careful consideration of the information available in the literature. It represents the most probable form for the copper-iron system except for a possible alteration of the line of solid solubility at the iron-rich end of the diagram in accordance with the recent investigation of Norton[10]. There are certain features of the iron-copper equilibrium diagram which are of particular interest in relation to the investigations which are described later in the present paper. It will be noted that immediately above the liquidus, iron and copper are miscible in all proportions, but as the temperature of the middle compositions is raised, the solution separates into two immiscible liquids. In the solid state there is varying solubility of copper in iron and of iron in copper. At room temperature the structure of alloys of intermediate composition consists of two phases, an iron-rich and a copper-rich solid solution. These phases are both primary and secondary. The

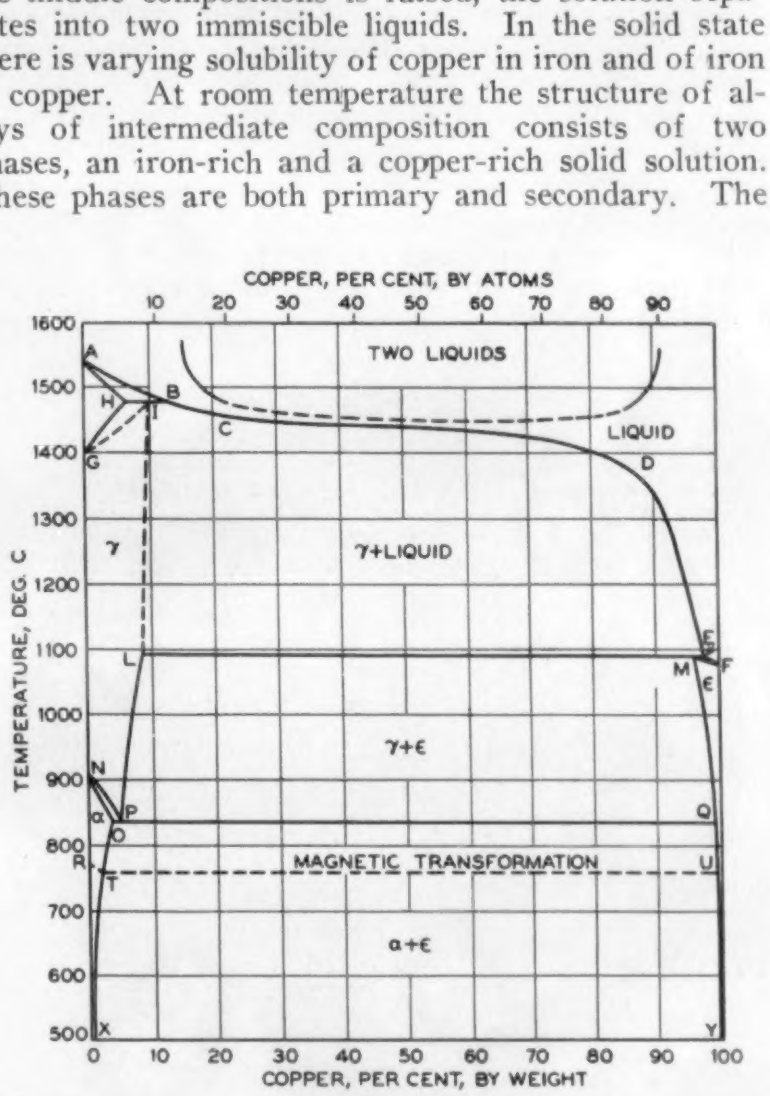


**Fig. 1. Proposed Equilibrium Diagram of the Iron-Copper System. Gregg and Daniloff.[1]**

primary phases are formed when the alloy solidifies and the secondary phases by precipitation due to the decrease in solubility of the component metals in the respective phases with decrease in temperature.

Interest in these alloys has been revived recently by published accounts of the age hardening effects obtainable with certain of the compositions. The investigations of Kinnear[11], Nehl[12], Buchholtz and Köster[13], and Smith and Palmer[14] have been concerned chiefly with the effects of small amounts of copper on low carbon steels, and a fairly complete picture of the behavior of alloys at that end of the diagram has been

obtained. At the copper-rich end of the system, the mechanical, electrical, and magnetic properties have been investigated by Johnson[15], Hanson and Ford[16], and Tammann and Oelsen[17]. For the most part, however, the investigations of this system have been concerned with the ends of the diagram and not with alloys rich in both copper and iron. Of the few studies

**Table 1.—Spectroscopic Analysis of Some Alloys of Copper and Iron**

| | Alloys Nos. 4 and 5 | Alloys Nos. 6 and 7 |
|---|---|---|
| Major Constituents | Fe<br>Cu | Fe<br>Cu |
| Impurities | Per cent | Per cent |
| Mn | 0.03 | 0.10 |
| Si | 0.03 | 0.10 |
| C | 0.01 | 0.01 |
| As | 0.003 | 0.006 |
| Zn, Ag, Sn, Pb | Faint trace | Faint trace |

concerned with the entire range of alloys of the copper-iron system, that of Burgess and Aston[18] was an attempt to determine the physical properties. Although no difficulty was experienced in the preparation of the ingots, it was found that the alloys containing from 7 per cent to approximately 80 per cent of copper were non-forgeable, and their properties were consequently not included in the paper. Ruer and Fick[5] also experienced difficulty in forging similar alloys, but were able to obtain electrical properties on samples by machining the cast rods to the desired diameter for testing.

Except for a number of investigators who have described the effect of small amounts of copper on the manufacture and properties of steel wire, to the authors' knowledge, there are no published accounts of the preparation and properties of copper-iron alloys in wire form.

**Fig. 2. Transverse Section of 0.75-In. Bar of 50 Cu-50 Fe Alloy as Cast. White—iron-rich constituent; dark—copper-rich matrix. Etched with $NH_4OH$ — $H_2O_2$. 125 diameters.**

## The Present Investigation

The present investigation is part of a review of copper alloy systems capable of yielding material in wire form suitable for electrical conductors. Since wire for this purpose should combine a relatively high electrical conductivity with high tensile strength and satisfactory corrosion resistance, the investigation of the copper-iron alloys was concerned principally with these properties. The outstanding characteristics of several of the compositions were brought to our attention by K. M. Simpson who has recently made an extensive study of the preparation of these alloys and has obtained considerable data on their properties. Results given in this paper were obtained partly on material furnished by Mr. Simpson, and partly on alloys prepared at Bell Laboratories.

Since the ultimate objective was a wire material with electrical and mechanical properties in a specified range, the procedure was not an extensive investigation of the entire series of copper-iron alloys, but was rather a study of the 50 copper-50 iron composition which preliminary examination had shown combined the desired properties. Preliminary studies of alloys on either side of this composition indicate that with higher copper content the requisite strength is not obtained, while with lower copper, the conductivity is decreased appreciably.

## Preparation of Material

In the preparation of alloys at Bell Laboratories, Armco iron and cathode sheet or wire bar copper were used. Melts of 3200 grams were made in a high frequency induction furnace in a silica crucible with a fairly heavy borax flux. No deoxidizer was added. No stirring of the melt, other than that normally occurring in the furnace, was necessary. Most of the melts were cast as 0.75-in. bars although several were cast 1.0 in. in diameter.

The alloys prepared were poured at temperatures only slightly above the melting point to minimize segregation which would be expected on the basis of the equilibrium diagram. Some segregation at the center of the cast bars was noted on visual examination, but was not serious since the tensile and electrical properties of different lots of material could be duplicated without difficulty. To illustrate the magnitude of segregation involved, the difference in copper content between the top and bottom of the 0.75-in. cast bars of a 50 Cu — 50 Fe alloy, 20 in. in length, was approximately 1 per cent. A number of ingots produced on a semi-commercial scale by K. M. Simpson[19] have been found to vary not more than 0.1 per cent in composition between top and bottom.

**Fig. 3. Transverse Section Same as Fig. 2. 500 diameters.**

Spectroscopic examination was made of several of the alloys prepared, and in addition to the major constituents, revealed impurities as listed in Table 1. Alloys Nos. 4 and 5 prepared on a laboratory scale and furnished by Mr. Simpson show less than 0.1 per cent of metal impurities, while samples Nos. 6 and 7, prepared under commercial conditions using scrap material, have approximately 0.2 per cent of manganese plus silicon as impurity. Only traces of other metals are present. The effect of these impurities on electrical conductivity, tensile strength and corrosion resistance are discussed in another section of this paper. The laboratory samples were all relatively free from impurities.

The typical structure of a cast bar of the 50 Cu — 50 Fe composition is shown in Figs. 2 and 3. The dendrites are iron-rich crystals, and the interdendritic material is the copper-rich matrix. This is the structure which would be expected on the basis of the equilibrium diagram shown in Fig. 1.

## Preparation of Wire

Since the commercial production of wire depends upon successful hot rolling of cast ingots, and since that phase of this alloy system has been controversial, the behavior of the alloys was observed under conditions permitting of reduction of the cast bars to 0.25-in. rod at elevated temperatures. At the start, cold swaging was used, but some difficulty was encountered with brittle borax inclusions which were not eliminated under the conditions of casting. The slag inclusions introduced no difficulties in hot swaging or hot rolling at 850 deg. C. and satisfactory rod for subsequent wire drawing operations was obtained. Castings of 1 in. and 0.75 in. diameter were rolled at 850 deg. C. to 0.25-in. size. A reduction of approximately 0.02 in. per pass was used, and the samples reheated after every second or third pass.

A number of different wire drawing treatments were utilized in the survey of these copper-iron alloys main-

**Table 2.—The Treatment and Properties of Some Copper-Iron Alloys**

| Sample | Nominal Composition | Treatment | Diameter of Wire, In. | Breaking Load, Lbs. | Ultimate Strength, Lbs. per Sq. In. | Electrical Conductivity, Per cent of I. A. C. S. at 20 deg. C. |
|---|---|---|---|---|---|---|
| 1 | 75 Cu-25 Fe | C.S. 0.75 in.-0.25 in., with anneals at 850 deg. C. | | | | |
| (a) | | C.D. 0.25 in.-0.040 in. | 0.040 | 173 | 137,600 | 25.5 |
| (b) | | Aged 1 hr. 250 deg. C. | 0.040 | 171 | 136,000 | 29.0 |
| (c) | | Aged 3 hrs. 250 deg. C. | 0.040 | 166 | 132,000 | 30.4 |
| 2 | 75 Cu-25 Fe | H.R. 850 deg. C. from 0.75 in.-0.25 in. Anneals at 850 deg. C. | | | | |
| (a) | | C.D. 0.25 in.-0.040 in. | 0.040 | 173 | 137,600 | 23.2 |
| 3 | 62.5 Cu-37.5 Fe | C.S. 0.75 in.-0.25 in., with anneals at 850 deg. C. | | | | |
| (a) | | C.D. 0.25 in.-0.040 in. | 0.040 | 191 | 152,000 | 18.1 |
| (b) | | Aged 1 hr. 250 deg. C. | 0.040 | 191 | 152,000 | 22.2 |
| (c) | | Aged 3 hrs. 250 deg. C. | 0.040 | 191 | 152,000 | 24.1 |
| 4 | 50 Cu-50 Fe | C.S. 0.75 in.-0.25 in., with anneals at 850 deg. C. | | | | |
| (a) | | C.D. 0.25 in.-0.040 in. | 0.040 | 242 | 192,600 | 16.0 |
| (b) | | Aged 1 hr. 250 deg. C. | 0.040 | 247 | 196,600 | 18.3 |
| (c) | | Aged 3 hrs. 250 deg. C. | 0.040 | 245 | 195,000 | 19.9 |
| (d) | | Aged 40 mins. 500 deg. C. | 0.040 | 201 | 160,000 | 29.9 |
| 5 | 50 Cu-50 Fe | C.S. 0.75 in.-0.25 in., with anneals at 600 deg. C. | | | | |
| (a) | | C.D. 0.25 in.-0.040 in. | 0.0403 | 305 | 239,000 | 23.8 |
| (b) | | A 600 deg. C. at 0.105 in. C.D. 0.105 in.-0.040 in. | 0.0402 | 243 | 191,300 | 24.2 |
| (c) | | A 600 deg. C. at 0.070 in. C.D. 0.070 in.-0.040 in. | 0.0402 | 204 | 160,500 | 24.9 |
| 6 | 50 Cu-50 Fe | C.S. 1.0 in.-0.25 in., with anneals at 600 deg. C. C.D. 0.25 in.-0.105 in. A 600 deg. C. | | | | |
| (a) | | C.D. 0.105 in.-0.040 in. | 0.040 | 238 | 190,000 | 14.9 |
| 7 | 50 Cu-50 Fe | C.S. 1.0 in.-0.25 in., with anneals at 600 deg. C. C.D. 0.25 in.-0.105 in. A 600 deg. C. | | | | |
| (a) | | C.D. 0.105 in.-0.040 in. | 0.040 | 302 | 240,000 | 15.8 |
| (b) | | A 600 deg. C. at 0.080 in. C.D. 0.080 in.-0.040 in. | 0.040 | 265 | 211,000 | 16.2 |
| 8 | 50 Cu-50 Fe | Same as 5 (b) | | | | |
| (a) | | C.D. 0.105 in.-0.040 in. | 0.040 | 230 | 183,000 | 29.8 |
| 9 | 50 Cu-50 Fe | H.S. 0.075 in.-0.25 in. at 850 deg. C. A 850 deg. C. C.D. 0.25 in.-0.105 in. A 600 deg. C. | | | | |
| (a) | | C.D. 0.105 in.-0.040 in. | 0.040 | 221 | 176,000 | 29.8 |
| 10 | 50 Cu-50 Fe | H.R. 1.0 in.-0.75 in. at 850 deg. C. C.S. 0.75 in.-0.25 in, with anneals at 850 deg. C. C.D. 0.25 in.-0.105 in. A 600 deg. C. | | | | |
| (a) | | C.D. 0.105 in.-0.045 in. | 0.0452 | 305 | 190,000 | 29.5 |
| (b) | | Sample 10 (a) tinned commercially | 0.0453 | 293 | 181,600 | 29.9 |

H.R. = Hot Rolled; C.S. = Cold Swaged; H.S. = Hot Swaged; C.D. = Cold Drawn; A = Annealed; Q = Quenched.

ly to get some indication of their behavior under a variety of conditions. Part of the wire was drawn from material of 0.105 in. in diameter, and part from wire rod stock 0.25 in. in diameter. In each case, the material was annealed at these diameters prior to the hard drawing operations. The results of the several treatments are listed in Table 2.

A noticeable feature of these alloys is the development of a fibrous structure in hard drawn wire. The

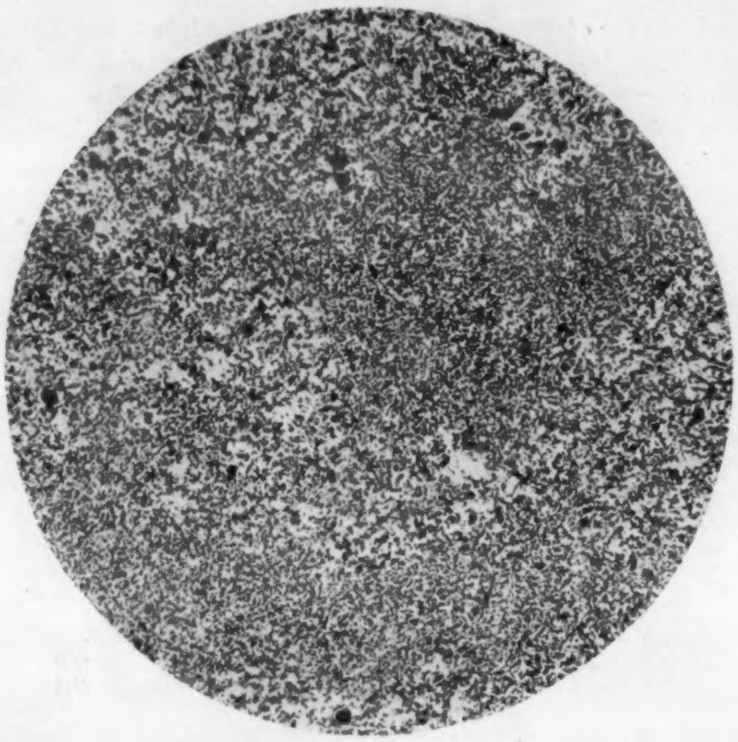

**Fig. 4. Transverse Section of 50 Cu-50 Fe Alloy Cold Drawn 0.25-0.040 In. White — iron-rich constituent; dark — copper-rich constituent. Etched with $NH_4OH$ — $H_2O_2$. 125 diameters.**

fibrous character of the material is shown in Fig. 4, a transverse section of a cold drawn wire of a 50 Cu — 50 Fe alloy (No. 5), and in Fig. 5, a longitudinal section of the same alloy. The dark sections are copper-rich material which has been etched by the $NH_4OH—H_2O_2$ reagent, and the light regions are iron-rich material. Both the iron-rich and copper-rich constituents have been elongated in the direction of drawing.

## Treatment of Material and Discussion of Results

In the general study of these alloys, it was the practice to prepare 18 AWG wire by hard drawing from 0.25-in. diameter, wire which was annealed at both 850 and 600 deg. C. When 600 deg C. anneals were used for alloy No. 5 instead of 850 deg. C. anneals as outlined for alloy No. 4 (which is from the same lot of material), higher values of tensile strength and electrical conductivity were obtained for the cold drawn samples. There was apparently a precipitation caused by the 600 deg. C. anneal which was not realized by the treatment at 850 deg. C. prior to drawing. The increase in tensile strength then resulted mainly from the hard drawing operations and the increase in electrical conductivity from the breakdown of supersaturated solid solution.

Samples 5 (a), 5 (b) and 5 (c) illustrate how the electrical conductivity is increased and the breaking strength decreased with less drastic drawing treatments. Alloys Nos. 6 and 7, of the same composition as No. 5, but with a greater percentage of impurities as shown in Table 1, have considerably lower electrical conductivities after identical treatment.

Alloys Nos. 8, 9 and 10 were used in various corrosion and tinning tests and indicate a fair approximation of duplication of ultimate properties of the 50 Cu — 50 Fe composition with variation of the fabrication operations. Several hundred feet of alloy No. 10 in the No. 17 AWG were tinned commercially without difficulty. No variations from the standard procedure for a phosphor bronze conductor were necessary. A slight annealing of the hard drawn wire occurred in the operation as may be noted in Table 2 where the tensile strengths and electrical conductivities before and after the treatment are compared.

The properties of the hard drawn copper-iron alloys may be further modified by subsequent aging treatment. This is illustrated by a number of alloys whose properties are given in Table 2. For example, the electrical conductivity of the hard drawn sample of alloy No. 3 was increased from 18.1 to 24.1 per cent by aging for 3 hrs. at 250 deg. C. The tensile strength was not affected. This increase in conductivity is due to precipitation from the supersaturated solid solutions.

As will be shown later, a 3-hr. aging treatment at 300 deg. C. of wire which has not been strained mechanically, does not have as great an effect on the electrical conductivity as a 250 deg. C. age has on hard drawn wire of the same composition. This, in general, is the usual behavior of age hardening alloys, and it is assumed that precipitation occurs in the strained material at a temperature lower than that necessary for unstrained material.

An aging treatment of 40 min. at 500 deg. C. for alloy No. 4 (d) increased the electrical conductivity from 16.0 per cent for the hard drawn wire to 29.9 per cent, but at the same time decreased the ultimate strength from 192,600 to 160,000 lbs. per sq. in. These

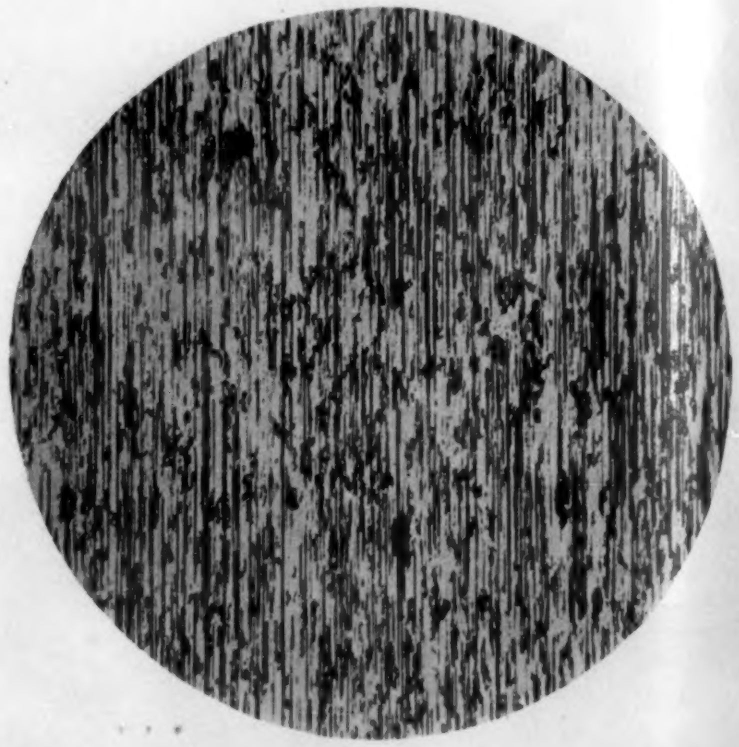

**Fig. 5. Longitudinal Section of 50 Cu-50 Fe Alloy Cold Drawn 0.25-0.040 In. White — iron-rich constituent; dark — copper-rich constituent. Etched with $NH_4OH$ — $H_2O_2$. 125 diameters.**

changes are probably attributable to the combined effects of annealing and precipitation from solid solution, the latter accounting mainly for the large increase in conductivity.

The aging effects obtained in the general investigation of the copper-iron alloys led to a study of the age hardening characteristics of the 50 copper — 50 iron composition. For this study, material was prepared in wire form 0.080 in. in diameter and in sheet form 0.100 in. thick. Both the wire and the strip material

were heated at 850 deg. C. for 1½ hrs. quenched in water and aged for various periods of time up to 5 hrs. at temperatures of 300, 400, 500 and 600 deg. C. A separate sample was used for each heat treatment and aging period. The results of these treatments are recorded graphically in Figs. 6 and 7.

It may be noted in Fig. 7 that, within the aging period, no definite increases in hardness within the experimental error were obtained for the samples at 300 deg. C. and 400 deg. C. In Fig. 6, however, where the variation in electrical conductivity with aging time is shown for the same material in wire form, it is evident that there is a precipitation from solution even for the samples aged at 300 deg. C. Based on the electrical conductivity of 100 per cent for the annealed copper standard, the increase in conductivity for material aged at 300 deg. C. for 5 hrs. is approximately 1.3 per cent greater than for the quenched samples, while that of the 400 deg. C. material is 8.9 per cent greater for the same aging period. Further aging of these samples (not shown in Fig. 6) caused a progressive increase in conductivity. At the end of 9-2/3 hrs. the conductivity of the 300 deg. C. wires reached 18.8 per cent, while after 7 hrs., that of the 400 deg. C. material was 25.7 per cent of the International Annealed Copper Standard.

Within the period of time considered, the best combinations of hardness and electrical conductivity are obtained with the 500 deg. C. treatment. Although the electrical conductivity continues to increase even after 5 hrs., the hardness begins to decrease after 2 to 3 hrs. The effect of hard drawing the material aged at 500 deg. C. is illustrated in Fig. 6 where it may be seen that a reduction in diameter from 0.080 to 0.040 in. decreases the conductivity of each of the aged samples by several per cent. Although a sufficient number of samples were not available for an accurate determination of the tensile strength of the material hard drawn following aging, a limited number of tests

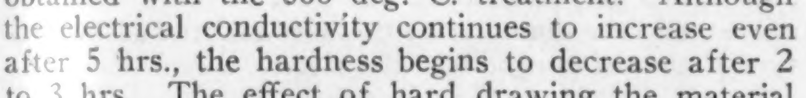


**Fig. 6. Effect of Aging Treatment on the Electrical Conductivity of a 50 Cu-50 Fe Alloy, 0.080 In. in Diameter.**

indicate that the tensile strength of the specimens increases with the aging period up to 2 hrs., and then decreases slightly with further aging up to 5 hrs. in a manner similar to the hardness variation of the 500 deg. C. samples shown in Fig. 7.

At 600 deg. C. the samples age rapidly and after ¼ hr. the hardness starts to drop and continues to do so until after 5 hrs. it is nearly that of the quenched material. The electrical conductivity for the 600 deg. C. samples is greater than for the 500 deg. C. samples after aging for ¼ hr. due undoubtedly to a more rapid initial precipitation from solid solution at the higher temperature. After ½ hr., however, the conductivity is lower than that of the 500 deg. C. samples for the same aging periods. It is reasonable to expect that the samples treated at 600 deg. C. would retain in solution more copper and iron than samples at 500 deg. C.

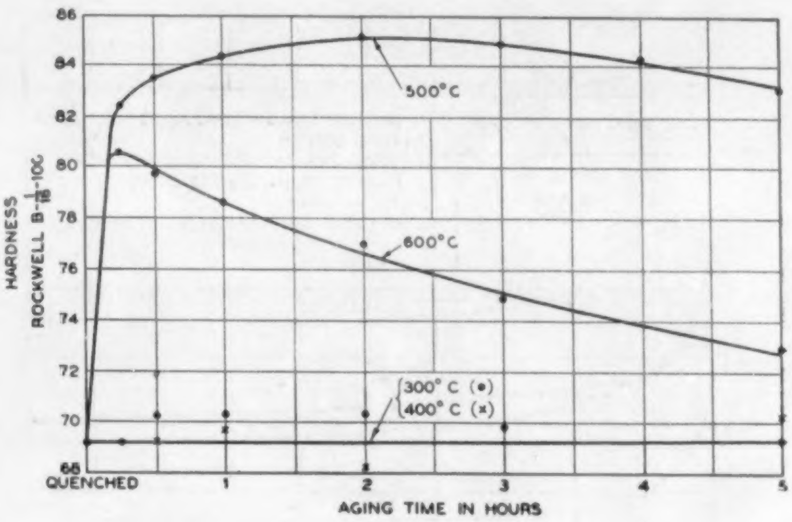


**Fig. 7. Effect of Aging Treatment on the Hardness of a 50 Cu-50 Fe Alloy.**

and the electrical conductivity would then be somewhat lower as equilibrium is approached because of a less complete precipitation from solid solution. This is illustrated in Fig. 6.

## Corrosion Characteristics

In the case of materials used for electrical wire purposes, atmospheric corrosion is of importance. While tinned coatings, insulation and braid afford some protection, any exposed areas at terminals are sources of trouble due both to the possibility of breakage and the accumulation of high resistance corrosion products at the binding posts.

Although there are a number of rapid tests for obtaining indications of the corrosion resistance of an alloy, the most useful and informative method is an actual outdoor test of the material. In this study, the behavior of a few of the alloys was observed under three different types of corrosion tests.* Salt spray and immersion tests, electrode potential measurements, and outdoor exposure tests of one year's duration.

The salt spray, acid immersion, and salt immersion tests were conducted on alloys Nos. 1(a), 4(a), and 5(b). Alloys Nos. 1(a) and 4(a), air cooled following an anneal at 850 deg. C., presumably retain a supersaturated solid solution of copper in iron, while alloy No. 5(b), annealed at 600 deg. C. contains a greater amount of precipitated material from the saturated iron-rich phase.

The tests made on these samples were as follows: (1) Salt spray, (2) Immersion in N/100 $H_2SO_4$, and (3) Immersion in a NaCl solution (100 g./L.). The results indicate that considerable galvanic action occurs. After a 7-day exposure period, heavy coatings of corrosion products were observed in both the NaCl and $H_2SO_4$ immersion tests. After an exposure for 32 days, all samples in the immersion tests had devel-

* These corrosion tests were conducted under the supervision of R. M. Burns and H. E. Haring of Bell Telephone Laboratories. The complete details of the electrode potential method as applied to numerous alloy systems will be described by them in a later publication.

oped heavy black or brown corrosion products. The iron-rich material of samples Nos. 4 and 5 was presumably dissolved from the surface during the long time corrosion and left a threadlike copper-rich material which cracked easily on bending, the broken end resembling a green stick fracture. The samples in the salt spray test were also badly corroded.

The study of the electrode potentials of the alloys was undertaken to develop a method of correlating

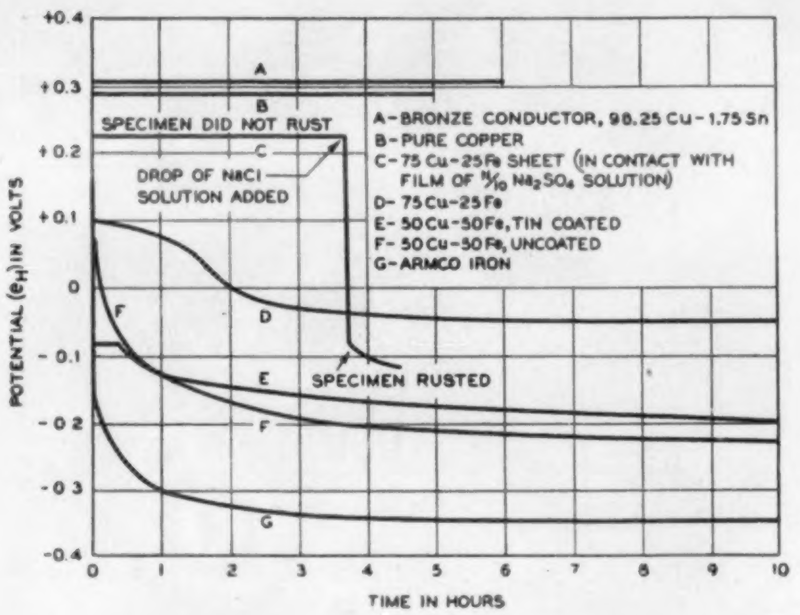


**Fig. 8. Time-Potential Curves for Wires of Various Compositions Immersed in N/10 $Na_2SO_4$ Solution.**

corrosion tendencies with the potentials of the metals against various electrolytes. Numerous attempts in this direction have been made in the past, but, in general, they have not proven to be particularly successful. However, results with these alloys and a number of others in recent studies of a similar nature indicate that, with certain refinements, this method should prove helpful in predicting the behavior of material under actual service conditions.

In brief, the method consisted of immersing a sample of the alloy in wire form in a tenth-normal solution of sodium sulphate and measuring continuously its potential over a period of time by means of a standard mercurous sulphate electrode and a recording potentiometer. The results obtained with several materials tested are shown by the curves in Fig. 8.

Assuming that the constant potential obtained for pure copper and the bronze conductor is an indication that no change is taking place, it can be predicted that these materials would not corrode in the environment selected. This was borne out by the fact that the specimens were not even stained. On the other hand, the copper-iron alloys behaved similarly to the sample of iron and were badly rusted in less than 10 hrs. The tin coating on sample E (Fig. 8) gave protection initially, but when corrosion commenced, the material behaved like the untinned sample.

To simulate more closely conditions which might exist in actual service, a sample of copper-iron alloy in sheet form was arranged for test so that atmospheric oxygen had ready access to the section where the potential measurements were being made. This was accomplished by making contact to the metal through a thin piece of filter paper moistened with the electrolyte. The results are shown by curve C in Fig. 8. No corrosion was noted after more than 3 hrs., so a drop of sodium chloride was added. The potential became more negative at once and within a short time corrosion had started. This indicates that the access of oxygen keeps the material in a passive or uncorrodible state, but when chlorides are present they destroy the passivity and allow corrosion to proceed.

The atmospheric corrosion tests run in conjunction with electrode potential tests consisted in exposing wire samples suitably mounted on the roof of Bell Telephone Laboratories in New York City. At intervals over a period of a year, measurements were made of the electrical resistance of the wire, surface contact resistance, and loss in tensile strength. The contact resistance measurements made between the copper-iron wires and the binding posts of a standard telephone drop wire terminal box did not show change within the experimental error over a one-year period. The electrical resistance and the breaking load of the exposed wire were altered considerably, however, as shown graphically in Fig. 9. Although both materials tested were badly corroded at the end of one year's exposure, sample No. 6, containing approximately 0.2 per cent of manganese plus silicon as impurity, was affected to a much greater extent than sample No. 9 which was relatively free of impurities. The breaking load of specimens of No. 18 AWG wire of alloy No. 6 decreased from an initial value of 232 lbs. to only 70 lbs. at the end of a one-year exposure period. In the same interval, the breaking load for samples of alloy No. 9 decreased from 222 to 138 lbs. Due to the decrease in the diameter of the wire and the accumulation of corrosion products, the electrical resistance was increased. Because of pitting in the samples, however, there is no direct relation between the breaking strength and the resistance.

From the various corrosion tests, it was concluded that while alloys of 50 copper — 50 iron might prove

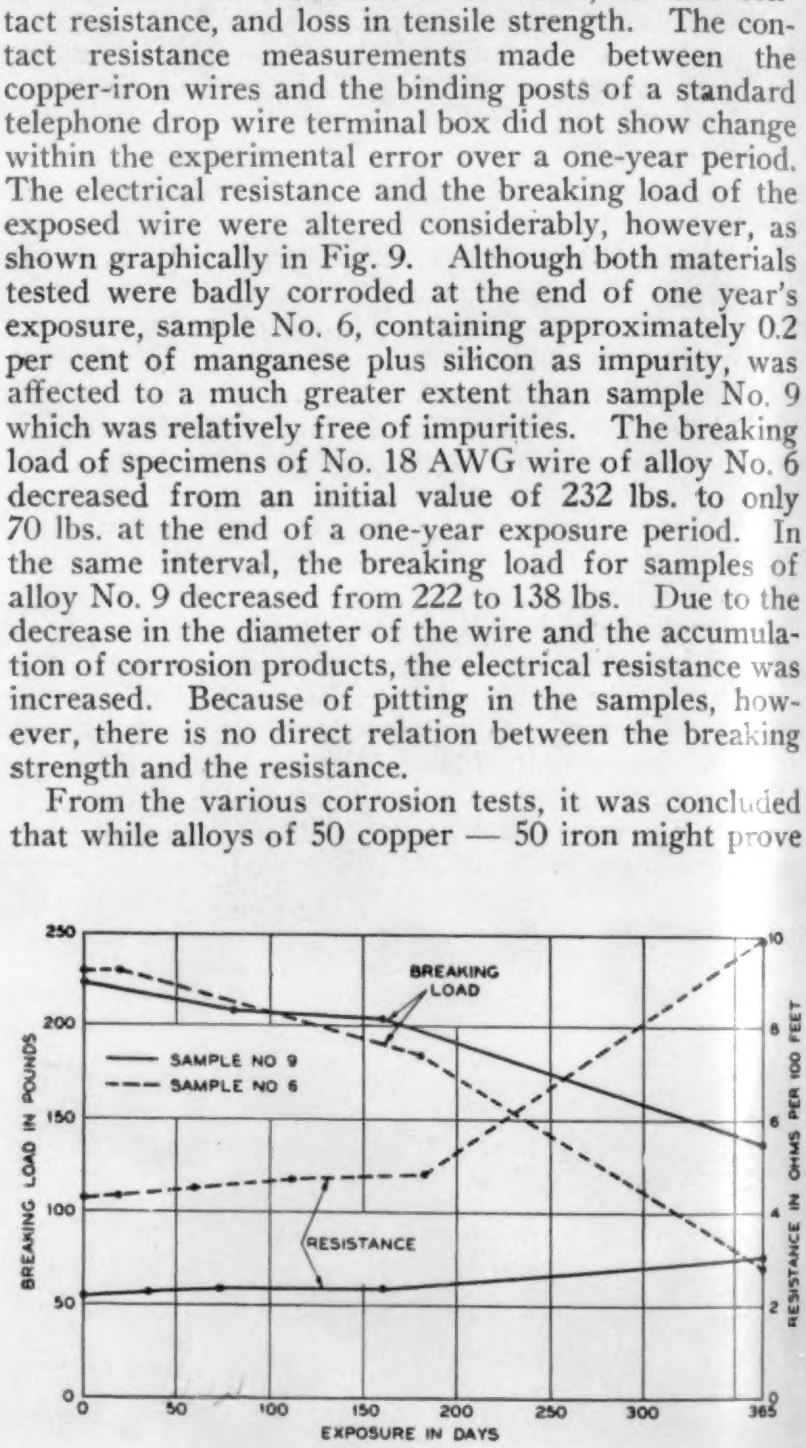


**Fig. 9. Variation of Breaking Load and Electrical Resistance of Samples of 50 Cu-50 Fe Alloy in Wire Form, 18 AWG, With Exposure to New York City Atmosphere.**

corrosion resistant in inland rural districts, they are unsuitable for use in marine atmospheres and would probably be unsatisfactory in most industrial atmospheres, particularly in regions near the sea coast. The corrosion resistance of the alloy is distinctly inferior to that of hard drawn conductivity copper and 1.75 per cent tin bronze alloy.

## Acknowledgment


The authors acknowledge their indebtedness to K. M. Simpson for his courtesy in permitting publication of that part of the data obtained on his alloys.

## Summary

Bars of copper-iron alloy 0.75 and 1.0 in. in diameter and 20 in. in length were prepared with compositions ranging from 75 Cu — 25 Fe to 37.5 Cu — 62.5 Fe without segregation sufficient to detect by differences in electrical and mechanical properties. These alloys were hot worked satisfactorily to 0.25 in. rod. The copper-iron alloys in the range investigated consist of a mixture of solid solutions of the constituent elements, the phasial relationships of which depend on the thermal treatment.

A few of the observations made concerning these alloys are listed below:

1. The alloys in the range investigated are of the precipitation hardening type, but do not require a drastic quenching treatment to retain a super-saturated iron-rich phase. The optimum combination of tensile and electrical properties is obtained in the 50 copper — 50 iron alloy by aging at 500 deg. C. followed by hard drawing.
2. High tensile strengths associated with desirable electrical conductivities can be developed for certain of the compositions. An alloy of 50 Cu — 50 Fe, for example, can be prepared in the No. 18 AWG with an ultimate strength of 180,000 to 190,000 lbs per sq. in. and an electrical conductivity of approximately 30 per cent.
3. The alloy of 50 copper — 50 iron can be satisfactorily tinned commercially.
4. Within the range of alloys studied, corrosion resistance decreases with increase of iron content. Various corrosion tests indicate that these alloys might prove corrosion resistant in inland rural districts, but that they are unsuitable for use in marine atmospheres and would probably be unsatisfactory in most industrial atmospheres, particularly in regions near the sea coast.


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# A Few Chuckles

## "Steel, High in Silicate Content"!

We quote from Taylor, F. J., "Southerners Build the Bridges."—*Colliers*, March 14, 1936, p. 18.

"The tremendous towers—four of them for the San Francisco-Oakland Bridge and two that support the whole weight of the Golden Gate bridge—are fabricated in factories. Open-hearth steel, *high in silicate content*, is rolled and drilled and fitted and bolted together on the ground and then taken apart and shipped to San Francisco, each piece carefully marked for its proper place." Italics ours.

Reminds us of the salesman who boasted that no other firm put as much S and P in their steels as his did.

## Smelting Furnaces Unnecessary!

The following is abstracted from an account in the *Foundry Trade Journal*, which got it from *The Far Eastern Review*, which quotes the Tokio *Nichi-Nichi*. It appears that a Jap student, Kikuchi, has patented a process alleged to have impressed Prof. Honda (though the Jap patent office had difficulty in grasping its fundamentals—patent offices seem to be alike the world over), and thus to have gained attention. An "electric beam wave" dissolves ores mixed with fuel in 30 to 60 seconds, thus making smelting furnaces unnecessary, and outdistancing present-day science by 100 years, since high grade steel can be made at a ridiculously low cost. It also allows production of Ir, W, Al and Cr at very low cost.

*Foundry Trade Journal* considers the most gratifying angle of the announcement to be that on hearing of this invention the South Manchurian Railway and another Japanese firm reconsidered their intention of ordering larger furnaces from Germany. Perhaps the Japs will no longer have to sweep the Pacific Coast clean of steel scrap, so we may also have cause for gratification.

We are personally disappointed that the opinion of Prof. Takashita was not included in the account.

## A Laywoman's Picture of the Steel Industry

In a gossipy column in a Pittsburgh daily Mrs. Florence Fisher Parry discusses the reliability of railway travel, ascribing it largely to the quality of the steel in track and train. She says "The most deserving of all our guardians of safety, are, after all is said and done, the steel makers, from the highest executive down to the humblest puddler." Wonder what her Pittsburgh readers think of puddled steel?—H. W. G.

# NOTCHED BAR TESTING—III

By S. L. HOYT

*Director of Metallurgical Research, A. O. Smith Corp., Milwaukee*

Continued from the February Issue

### Fibrous and Cleavage Fractures

THE WORK OF LUDWIK AND SCHEU on notched tensile bars has already been referred to. It was mentioned in particular that the notch effect manifested itself by restricting the flow of metal in the vicinity of the notch; by making plastic deformation more difficult the metal tended more and more to break by cleavage on a plane normal to the axis of the bar. Ludwik[12] analyzed the stresses at the notch in terms of the normal stress which acts to produce cleavage and the maximum shear stress which acts to produce plastic flow in the bar at 45 deg. to the axis. The metal takes the "path of least resistance" under a given stress system and either deforms or fractures, depending on the resistance to both plastic flow and cleavage and on the magnitude of the stresses acting in both directions. The application of this idea to the notched behavior of ductile metals is very direct for the notch influences the stress system in such a way that the tendency to cleave is greatly accentuated.

When a plain bar is stressed in tension the normal stress is actually twice the maximum shear but it is small in comparison to the resistance to cleavage when the shearing stress at 45 deg. becomes great enough to overcome the resistance to deformation. This situation holds during deformation up to and even past the point where necking commences. (Of course we are here referring to normally ductile steels). The notch materially alters this situation, and in three ways. Referring to Fig. 2 we may consider the bar diameter to be 18 mm. The notch alters the relationship between normal and shearing stress because, while it materially reduces the cross section which supports the normal stress, it has relatively little effect on the resistance to shear at 45 deg. to the axis.

Secondly, and this is the central point of Ludwik's hypothesis, the lesser stressed metal around the notch stiffens the metal against contraction and sets up a triaxial tensile stress in place of the simple axial stress of the plain bar. The result is that the normal stress at the notch mounts to much higher values before producing the necessary shearing stress to produce flow of metal. By increasing the severity of the notch effect this normal stress finally becomes equal to the cleavage strength before the metal flows plastically. While the load on the bar is greater, the deformation falls off and the work to rupture becomes much less, and the fracture changes from fibrous to cleavage.

Thirdly, the normal stress is severely concentrated at the apex of the notch. A relatively low tensile stress may set up a normal stress at that point which exceeds the resistance of the material in that direction, and a crack forms if the metal is notch sensitive. Formerly considerable weight was given to this stress concentration as a factor in notch behavior but the current trend of thought is to minimize its importance.

Personally I incline to the first effect as being of greatest moment, but the whole problem must await more precise and quantitative data. Assuming static loading, that metal has the best opportunity to show tough behavior when notched which has a high cleavage strength and a low resistance to plastic flow and whose ratio of cleavage strength to resistance to plastic flow is not too greatly decreased by deformation. Under impact the relationship between the resistance to cleavage and to deformation would not be greatly altered as the striking velocity increases.

It will be observed that this idea departs from that of Moser in an important particular. Moser correlated the impact value directly with the volume of metal deformed,—a low impact value meant that only a small amount of metal was effective in absorbing energy. According to Ludwik's hypothesis the low impact value would come from a change in the behavior of the metal,—instead of deforming, the metal would break by cleavage before deformation set in so that the element which is largely responsible for the absorption of energy, deformation, would be missing. These two fracture types are shown in Fig. 6. Maurer and Mailander, in their extensive study of the effect of temperature on the notch behavior of steel, applied Ludwik's hypothesis to an analysis of their findings.[13] So illuminating and successful was this application that analyses of notch behavior have ever since been guided by the Ludwik hypothesis. The significance of fibrous and cleavage fractures has been emphasized and fully discussed by Fettweiss, whose work may be referred to if more details are desired.[14]

In brief Fettweiss pointed out the significant relationship between fracture type and energy absorption. Of course this had been observed before and the appearance of the fracture had long been used as a guide to judge the quality of the steel, but Fettweiss insisted that this was a central point of notched bar behavior. This was well illustrated by the rapid change at temperatures above and below room temperature. Above the zone of spread the fibrous fracture was typical, below the zone of spread it was the cleavage type, while those bars which broke in the

zone of spread showed both types. There values were apt to be high, or low, or intermediate. Schwinning and Matthaes had observed that the impact diagrams showed steep vertical branches which were connected by sloping branches. Fettweiss held that these corresponded to cleavage and fibrous fractures respectively. As the tendency to rupture by cleavage became greater, for example by a coarsening of the grain size, the transition temperature was shifted to higher temperatures. Fettweiss also held that the effect of temperature was analogous to that of the width in that both variables alter the character of the fracture.

### Technical Cleavage Strength

The success of Ludwik's hypothesis focussed attention on cleavage strength and its importance as a material constant. Obviously it would be worth while to determine the cleavage strength of steel and to correlate it with the resistance to plastic flow. This might make it possible to analyze the notch behavior of metals to secure a much clearer understanding of the factors affecting it. It was felt at one time that the tensile test itself could be made to give the necessary information, for if one calculated the true normal stress at rupture for the series of plain and notched bars, it appeared that this figure was essentially constant and therefore independent of the amount of deformation which preceded final rupture. One had then but to compare the true rupture strength with cleavage strength, far from being independent of deformation, varied in a definite and unique way with deformation. This contribution is very largely the result of the labors of Wilhelm Kuntze of Berlin-Dahlem.

Kuntze's first contribution to the problem of determining cleavage strength was the development of an accurate and reliable lathe procedure for machining the notch in a cylindrical specimen.[15] This enabled him to produce notches of different angles and depths and with an essentially strain free condition at the apex, though with a sharp radius. The basic idea for the determination of the cleavage strength was that a sufficiently sharp or effective notch would eliminate all plastic deformation and give a perfect cleavage fracture. The corresponding stress would be the true cleavage strength of the material. Kuntze then proceeded to test a material with a series of bars whose notches decreased in angle and increased in depth until the notches became no longer suited to accurate testing. By extrapolating the breaking stresses to zero angle and zero cross sectional area at the base of the notch, the correct conditions were realized for a determination of the cleavage strength, or the "technical cleavage strength" to be more precise. Kuntze's work leaves little doubt that his determinations of the cleavage strength are essentially correct. In one instance he calculated that the cleavage strength of 0.18% C steel was 86 kg per sq. mm and in his determinations

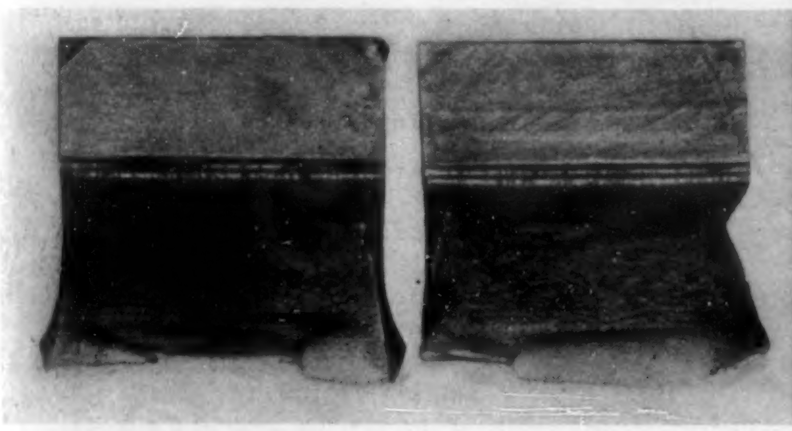
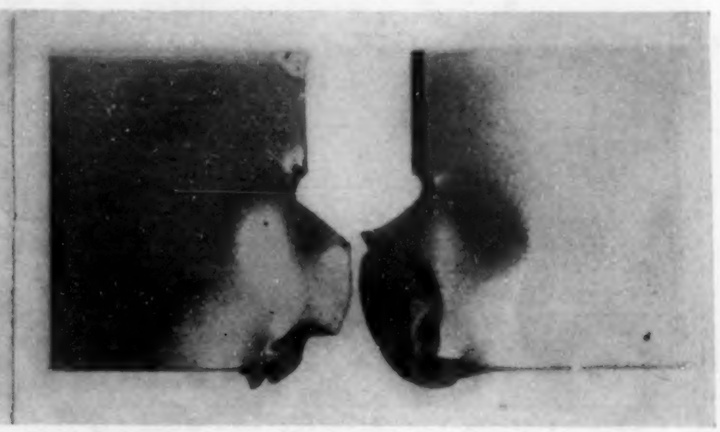


Fig. 6—End View—Tough Fracture.



Side View—Tough Fracture.

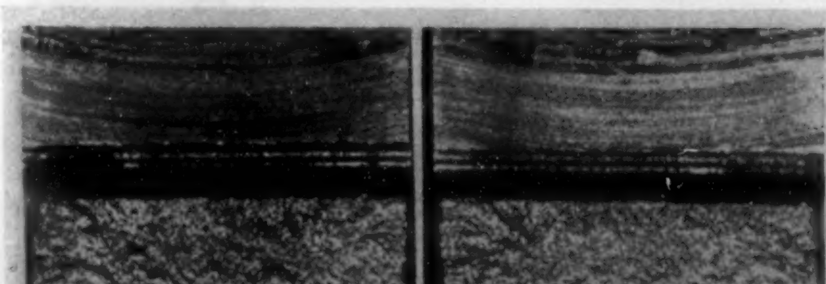


Fig. 6—End View—Brittle Fracture.

Side View—Brittle Fracture.

the yield point and tensile strength for the former would give the cleavage strength of the material and the latter would give the resistance to deformation.

On this basis the straight tensile test would yield information on the notched behavior, a feature which would place the tensile test in a favored position in measuring toughness. Unhappily for any such simple correlation between the tensile test and notched bar tests this early work did not bear fruit. This was principally because subsequent work showed that the of the point, he approached this point so closely that he actually secured a breaking stress of 75 kg per sq. mm. The tensile strength of this steel was 42.5 kg per sq. mm or 60,000 lbs. per sq. in.

Among the first findings with this new method was the way cleavage strength varies with deformation. (Just a word of caution here seems necessary. It has been advanced that this determination does not give a material constant because the load to fracture the test bar is increased by the triaxial stress at the

notch. I give Kuntze's presentation here of what he calls the cleavage strength.) In one series he strained plain tensile test bars by various amounts even past the point at which necking began and into the severely necked portion. At these various stages of uniform and non-uniform elongation, he determined the cleavage strength and found that it rose rapidly with deformation until after necking had set in. Shortly thereafter the cleavage strength fell rapidly and in such a direction that it coincided with the true stress at rupture. In other words when the true stress became equal to the cleavage strength, the bar broke. In the initial state and at all intermediate degrees of deformation the cleavage strength lay well above the true normal stress on the test bar. The results obtained with a mild steel are shown in Fig. 7. There

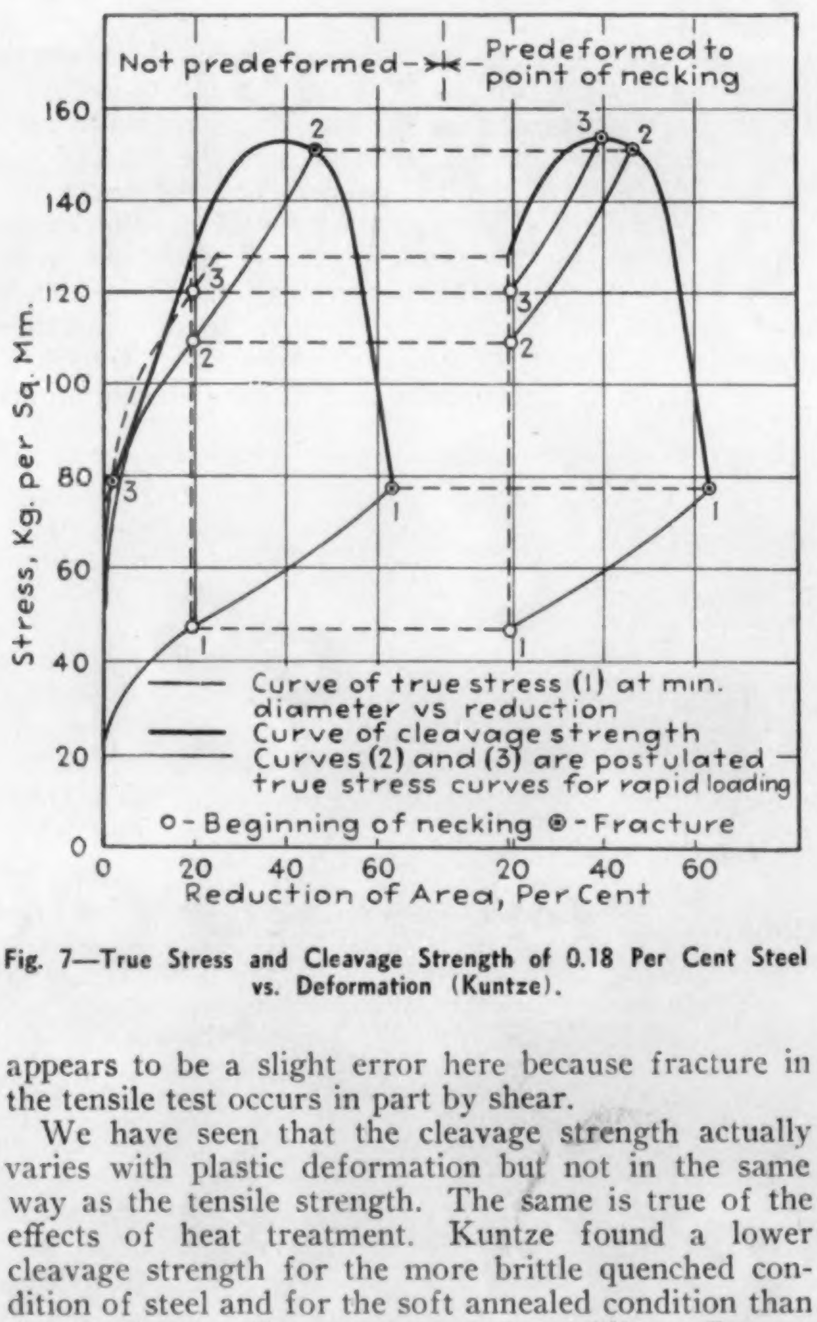



**Fig. 7—True Stress and Cleavage Strength of 0.18 Per Cent Steel vs. Deformation (Kuntze).**

appears to be a slight error here because fracture in the tensile test occurs in part by shear.

We have seen that the cleavage strength actually varies with plastic deformation but not in the same way as the tensile strength. The same is true of the effects of heat treatment. Kuntze found a lower cleavage strength for the more brittle quenched condition of steel and for the soft annealed condition than for the intermediate heat treated condition. Copper, aluminum and brass were also experimented with and they were all found to show the same variation with plastic deformation as the steel did.[16] This is important here for it shows that if a metal can begin to deform at the base of the notch, it increases at once in cleavage strength in the correct way to permit still further plastic deformation to occur, all of which enters into the absorption of energy. (Note—After a small deformation, the cleavage strength increases at a more rapid rate than the resistance to deformation.)

The effect of increasing the speed of deformation on the behavior of steel was introduced by speculation. It is known that the resistance to deformation increases with the velocity at which the deformation is required to proceed. There seems to be no such relation between cleavage strength and velocity, for cleavage occurs with no deformation. As the speed of deformation increases, the curve of true stress vs. deformation lies at higher and higher values of stress for given values of the deformation—see curves 2 and 3 of Fig. 7. With the curves of cleavage strength vs. deformation being unaffected by speed, the two curves may intersect and if they do so at a low value of the deformation, the bar breaks with a brittle fracture. Thus may we account for the behavior of a normally ductile material which is sensitive to speed of deformation. By the same token if that same material be deformed as a plain bar by some 20 per cent or until its cleavage strength has been materially raised, the same increase in velocity may have but relatively little effect in producing the brittle fracture. This is, of course, speculation, and is not as yet amenable to direct experimental verification.

Kuntze has shown by his work that the cleavage strength of Ludwik is a definitely determinable property, or (statistically mean) material constant. The resistance to deformation, which is the second material constant required for Ludwik's hypothesis, can be secured from the tensile curve when the true stress is plotted against the reduction in area. The figures actually used are the yield point or (and) the tensile strength. The use of these two constants may have rather far-reaching consequences in other branches of the testing of materials besides that of notched bar testing and, as Kuntze points out himself, they, together with the absolute shear strength, may provide the common denominator by means of which the various mechanical tests of metals can be correlated. Over 70 years of experimental engineering have so far failed to provide such a common viewpoint. For our present purposes Ludwik's hypothesis simplifies speculations on notched bar behavior and also should help establish a more rational method of determining the notch sensitivity of steel.

## Testing Notch Toughness

We come to a point now where we must try to figure out what this is all about and where we must, if possible, satisfy the engineer who deals with metals in terms of test data and the metallurgist who treats them from the metallurgical point of view. The former should realize that the integrity of his structure in service *may*, and frequently does, depend on a property which his tensile test does not measure. I refer to the cleavage strength of the undeformed metal and its ratio to the elastic limit. He should realize that the notched bar test in suitable form is really designed to secure that information in a simple and practical way. The metallurgist who, almost instinctively, would insist upon heat treating an important steel casting and would quench a temper brittle steel from the drawing operation, should realize that the test gives him a positive check on these and other quality factors. Perhaps the first point to be taken up here is the selection of a criterion by which to judge quality.

In the tensile test, if one steel has a proportional limit of 50,000lb. per sq. in. and another one 100,000 lbs., we are correct if we say that one steel necessarily has one half the elastic strength of the other. In the notched bar test if one steel breaks with an energy absorption of 20 ft. lb. and another with 40 ft. lb. we dare not say that the former necessarily has one-half the notch toughness of the other. In the same way if

two steels absorb just 20 ft. lb. each, we dare not say that they are necessarily equally notch tough. I place the accent on "necessarily." This attitude towards evaluating the results of the notched bar test, though possibly unorthodox, is demonstrably correct and I shall take that up directly. That being the case, we should then account for the undoubted utility of the figure for energy absorption in this test in over three decades of use.

I believe the answer is that any one of the routine methods of notched bar testing is capable of eliminating *most* material which is really deficient in notch toughness. In many instances this is accomplished even without the use of a notched bar test; here the methods of manufacturing the steel, inspection for defects, control of mechanical and heat treatments, and the usual chemical and physical tests are sufficient to reduce the hazards of serious notch brittleness. Even so we may expect this practice to pass some material into service which is really deficient in notch toughness for the procedure includes a definite blind spot. The addition of a standard notched bar test will eliminate most of those cases, which will leave only relatively few, the detection of which would require a more searching test. At this place I believe it worth while to offer a specific case of notched bar testing which bears on all three points (i.e. the use of no test, the use of a standard test, and the use of a special test) and particularly because it will serve as an introduction to my comments on methods of testing.

A number of years ago, while at the research laboratory of the General Electric Co., it occurred to me that notched bar testing should be utilized in a practical way for more important steel forgings and castings. The General Electric Co. has many such parts in its manufactures and naturally lays great emphasis on the reliability of its products. Dr. Whitney was quite sympathetic to the idea and proposed that I discuss the situation with J. A. Capp, chief of the Testing Laboratory. Mr. Capp explained at some length that they had broken many test bars in their work but that so far they did not feel justified to adopt the notched bar test as an acceptance test. If I could prove its practical value, they would be glad to use it and would cooperate in anything I cared to do.

After materially reducing the cost of preparing test bars, which seemed highly desirable, the first step was the development of a modified Moser test. With the 10 mm. bar this involved breaking bars ranging from 5 to 30 mm. wide, or from one half width to triple width. Even though the steel was a high grade forging steel the triple width bar broke with less total energy absorption than the single width bar. Of course the steel was known to be strong and ductile in the usual sense. This preliminary work suggested the desirability of breaking half width, single width, and double width bars.

After the development of a modified Moser Test, G. R. Brophy, of the staff of the research laboratory, took over the assignment of testing out various standard steels used by the company, the more completely to check up on the possible utility of the new test. This work was done with the cooperation of George Wright of the testing laboratory who later took it over in a more specific study of parts which had failed in service from no apparent or ascertainable reason. This work was later described before the Schenectady Chapter of the (then) American Society for Steel Treating. At that time Mr. Wright brought out very vividly that certain failed parts which had the correct composition, had been given standard (and correct) treatments in manufacturing, and had the correct tensile properties and even microstructure, showed up a definite weakness in the notched bar test. This point was checked up on as many failed parts as were available for the study, with parallel work on similar tests on current production.

It may also be of interest that the tensile impact tests on plain bars in all cases showed normal energy absorption, elongation and reduction of area and did not detect any difference between good and bad material. The results were so clear that one who was responsible for the quality of steel in important forgings or castings could not conscientiously pass material into service which, though it were in all other respects of unimpeachable quality, failed to pass the requirements for notch toughness. It is my understanding that this requirement has been continuously applied wherever justified by the importance of the part and the service it would be called on to render.

Let us now inquire into the test that was developed out of this work. For some time bars of half width, single width, and double width were broken. Later the half width bar was eliminated as not giving information not secured from the single width bar. The latter bar gave what might be called the normal impact value and if it came obviously low, the material would be rejected. In some important cases, the single width bar gave a suitable impact value but the double width bar gave too low a value. That is interesting and important. It shows that Mr. Wright felt that a material, whose notch sensitivity was so great that it showed up poorly in the double width bar, was unsuited for the service in question even though it passed the standard test. If only the standard, single width bar had been used, this material would have passed into service and would probably have failed, for that is what Mr. Wright's studies showed, and to some would show that the test "doesn't mean anything" and does not "correlate with service." For the service in question the assurance was needed that both single and double width bars were tough. Had we gone further and broken triple width bars too we would probably have found no material to give three times the impact value of the standard bar, which is why I did not recommend its use.

Note: Since this was written, Mr. Wright has shown me triple width bars which broke with three times the energy absorption of the single width bar.

I believe this example illustrates the point already made. A large amount of satisfactory material would be passed into service if only the usual chemical, physical, and microscopical tests were used, in addition to normal inspection. Some service failures would occur for a reason not explained by such tests or inspection. The use of a standard Charpy test with a single width bar would sort out some of this type but would still permit, and did actually permit, some objectionable material to pass. The increase in the severity of the test which came from adding the requirement that the double width bar show double the impact value of the single width bar practically eliminated hazards from this source. Doubling the requirement for the impact value of the single width bar would not have served the purpose. For one thing it would have been impossible to meet the strength requirements. Furthermore, while that would have insured getting twice as tough material for the particular notch effect of the single width bar, it would still

have failed to provide the check on notch sensitivity that comes with the double width bar. The exigencies of the individual case should be permitted to govern the testing practice, either that no notched bar test is necessary, or a simple test is sufficient, or a more sensitive test is required.

The strength requirements of a steel are very easily settled, and we need not mention them here except to point out that no such simple procedure is available for determining what degree of notch toughness is required. One method of approach is that of studying failed parts which was adopted by Mr. Wright and about the same methods have been used at our Watertown Arsenal and elsewhere. By comparing the impact values of failed parts with test results on similar material a reasonable requirement can be set up. A more complete basis could be set up for such work by making use of the principles discussed previously. One would determine the impact value for a series of test bars in which the notch effect varied, and then by testing at different temperatures and with different striking velocities, mainly statically and dynamically, the effects of those two variables would be ascertained. By repeated check tests on different lots of steel a standard behavior for that steel could soon be established, whereupon variations due to composition and treatment could likewise be determined.

This work would establish a complete picture of the steel in question. With the service requirements in mind, it would be relatively simple to select the number of test bars and the proper test conditions for the individual case. This is not a simple procedure but it has the virtue of eliminating the uncertainty which is inherent in the test. If the service did not warrant using the entire test procedure, the basis laid by the ground work would serve as a guide to the very best test conditions for one test. Fortunately the usual laboratory temperature comes at about the range where many steels show a low impact value if not in a good condition, so that with a simple yet properly selected test, one could eliminate most cases of notch brittleness.

*(To be concluded)*

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# A LETTER TO THE EDITOR

## Grain Size in Forging

*To the Editor:* The "Highlights" in METALS AND ALLOYS are always interesting and never fail to attract my attention. At the same time we feel it is a privilege to take exception to any opinions we find written there. Do you agree with me thus far?

In our experience with grain size in forgings we have found important facts:

(a) Coarse grain steels (1-4) in SAE 1045 forgings will rupture at the flash line when trimmed if they are *not* normalized after forging—not 100 percent, but about 20 percent, depending on the grain size. This rupture will not be apparent until the forgings are heat treated, (water quenched). Normalizing is sufficient to prevent water cracks in the flash line since there is no rupture in the trimming to start the cracks.

(b) Fine grain steels (6-8) in SAE 1045 forgings do not rupture in trimming even without normalizing after forging. Nor do they develop water cracks when quenched.

(c) Intermediate grain size in the 1045 steels is apt to have the characteristics of both fine and coarse grain.

(d) Assuming an average strength of 60,000 lbs. per sq. in. in the 1045 steel forgings in the "as forged" condition, the strength may fall as low as 27,000 lbs. *after* heat treating, (1550—water 650 draw), with a high of 115,000 lbs. in the same lot. The weakness, (27,000) can be traced to a water crack in the flash line, originating from the rupture in trimming without normalizing. Uniformity can be reached by either normalizing the coarse grain steel or employing the fine grain (6-8). No duplex or intermediate grain size will guarantee freedom from ruptures and water cracks. If either steel is *not* heat treated, the strength is *not* affected by grain size, even if ruptured in trimming.

(e) Another noticeable defect can be found on forgings of variable section which are subjected to a drastic quench. One would not ordinarily attempt to produce this is possible in fine grain steel without danger of a 600 Brinell on a 1/4-in. section of 1045 steel. Still this is possible in fine grain steel without danger of water cracks. But in coarse grain or intermediate, (duplex), grain (2-3-4-5) 1045 steel, this drastic quenching would result in a certain percentage of water cracks. We have found a steel of 0.48 carbon, 0.70 manganese, which showed 4-5 grain develop cracks in hardening where the same heat of steel with 6-8 grain size would be absolutely free from cracks. On further investigation we found the aluminum content on the cracked forgings (4-5) to be 0.015 percent and on the good forgings (6-8) to be 0.025 percent, which would indicate that the grain size was responsible for the cracks. No impact tests were made due to the small section available.

So, in reading the paper (referred to in "Highlights"), as published in the ASM *Transactions* of September, 1935, on "Effect of Grain Size Upon Some Physical Properties of Medium Carbon Steels," I am inclined to agree with the authors that the grain size does have a bearing on the results in heat treating. The percentage of failure will vary of course with the grain size but, as the authors state, cracking results in water quenching 1045 steel sections below 3 in., when there is coarse or intermediate grain size.

Years ago, when we had water cracking, the operation was changed to oil or less drastic medium. Now it is possible to produce maximum hardness, wearing properties, and strength with the fine grain size steels.

I would venture to say that normalizing is necessary on the coarse grain steel forgings due to the lower coarsening temperatures, while the fine grain steel forgings are finished below the coarsening range and therefore appear more nearly refined after forging and do not necessarily need the refining to prevent rupture during trimming.


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Metallurgist

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# ANOTHER LETTER TO THE EDITOR

## Phosphorus in Low Carbon, Low Alloy Steels

*To the Editor:* The writer was much interested in the report on "Phosphorus as an Alloying Element in Low Carbon, Low Alloy Steels" which appeared in METALS & ALLOYS of January, 1936.

The duplex structures of Figs. 3 to 8 raise a question which Messrs. Lorig and Krause may be in a position to answer in some future report. On page 10 of the January issue one of the duplex structures is described: "As Fig. 4 shows, this contained a very small amount of gamma." Does this mean that gamma iron actually exists at alpha grain boundaries, as the photomicrograph seems to indicate? Again, in referring to their Figs. 7 and 8, Lorig and Krause state: "The amount of the light constituent, ferrite, shows that in steels with such carbon . . . etc." This implies that the dark constituent is not ferrite. The authors apparently observed similar duplex structures in their alloys containing comparatively low phosphorus contents, about 0.07 per cent P, and from their Fig. 1 it appears that such an alloy was obtained in the pure gamma form upon quenching from 1900 deg. F.

There is considerable doubt as to whether such a comparatively pure material can be preserved in the gamma form at room temperature. In reviewing the earlier literature on the Fe-P and Fe-C-P alloys it is difficult to find a definite statement indentifying any phase present at room temperature in the duplex alloys as the gamma phase. Several writers have indicated, however, that their duplex structures were the result of phosphorus segregation at elevated temperatures.

It is the writer's opinion that all duplex structures of this type may be explained by means of phosphorus migration and segregation. Whiteley[2] and others have already been most successful in interpreting the structural effects caused by phosphorus segregation in carbon steels. It is now well known that phosphorus is much less soluble in gamma iron than in alpha and that it has a strong tendency to migrate out of the gamma zone whenever possible. Whiteley writes: "This diminished solubility of the phosphorus in the gamma iron phase, formed under the above conditions, is probably due to the presence of carbide in solid solution. . . . On the other hand, it is possible that the partition coefficient may be independent of the carbon content of the gamma iron and may vary only with the temperature." The Fe-P diagrams of Fig. 2 in Lorig and Krause's paper indicate a considerable difference in solubility of phosphorus in the alpha and gamma phases in alloys of low carbon content.

With this in mind, the small islands in Fig. 4 of Lorig and Krause's paper may be described as regions which existed as gamma iron at 1900 deg. F. but reverted to alpha upon quenching. The pseudo grain boundaries which outline these areas may then be due to a drastic change in phosphorus content due to loss of phosphorus while in the gamma state.

Figs. 2 to 6 show the effect of a copper-depositing etching reagent on the quenched wrought iron sample mentioned above. The etchants used were a concentrated solution of picric acid in alcohol followed by a short application of the following solution: 2g. $CuCl_2$, 1 ml. conc. HCl, 50 ml. alcohol. The dark areas represent copper colored areas of the original specimen. Stead and others have proved conclusively that copper precipitates most readily on the phosphorus-poor regions of a segregated steel or iron. The pseudo gamma

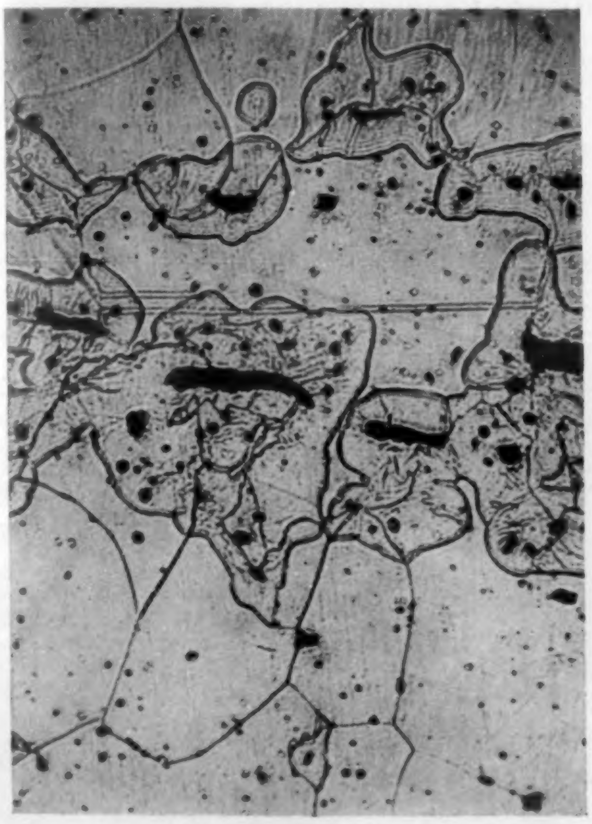

Fig. 1. Magnification 200 Diameters.

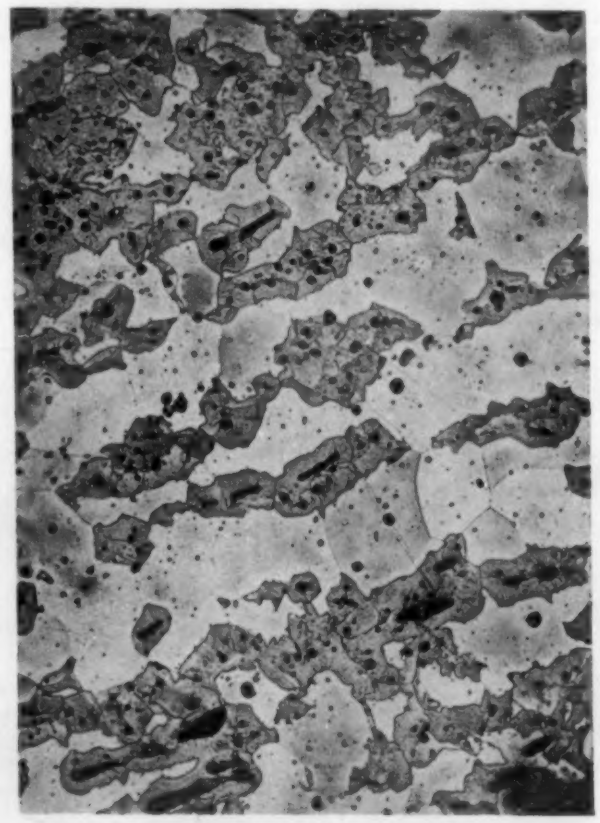

Fig. 2. Magnification 100 Diameters.

islands in these figures were well coated with copper after short applications of the above etchant. Fig. 6 represents a slightly longer etch, showing the first stages of copper deposition on the phosphorus-rich areas. The regions of highest phosphorus content are the white borders surrounding the phosphorus-poor dark areas. This is to be expected upon considering the mechanism of segregation described above. Whiteley showed the corresponding condition in carbon steels after quenching from temperatures between $Ac_1$ and $Ac_3$.

Fig. 5 is a tracing of the true ferrite grain boundaries of Fig. 4. The Neumann bands of Fig. 4 again aid in defining the true crystal boundaries.

An excellent photomicrograph showing duplex structure appeared in a report: "Quality Standards for Wrought

The writer hesitates to reopen this troublesome question. Nevertheless, the almost certain commercial application of phosphorus as an alloying element in certain tonnage steels of the future, and its continued use in wrought iron seem to justify some further consideration of the migratory habits of phosphorus.

Since reporting a progressive series of duplex structures in quenched commercial wrought iron[1], the writer produced the structural condition shown in the accompanying photomicrographs, Figs. 1 to 6, by cold hammering a small pipe section after quenching in water from 910 deg. C. The long Neumann band which traverses both "gamma" and "alpha" regions of Fig. 1 may be taken as evidence of the crystalline continuity of the entire region.

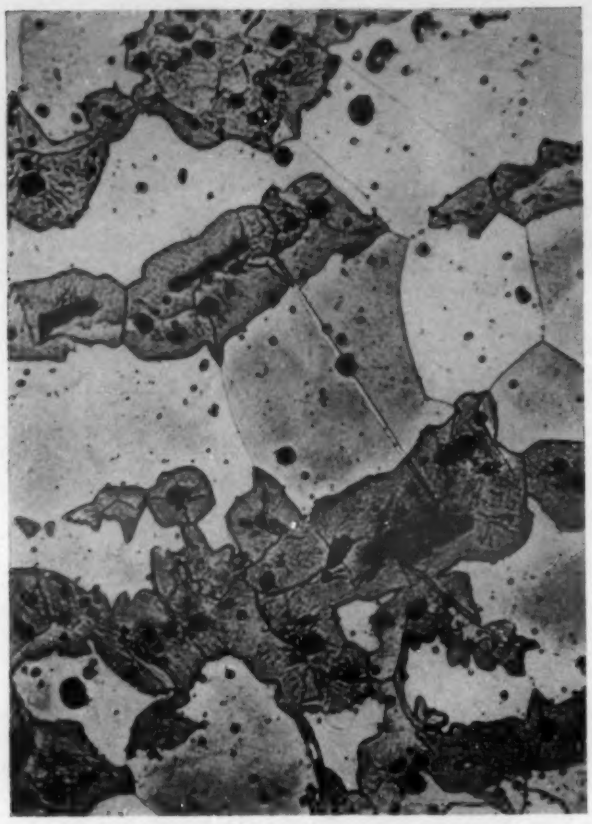

**Fig. 3. Magnification 200 Diameters.**

Iron."[3] It is explained as follows: "The segregated or banded nature of the phosphide distribution in the iron matrix is likely to cause a zone of brittleness, especially as a result of high heat influences in welding, etc."

It is easy to see how rapid cooling from the welding heat might produce zones of segregation as shown, even though the phosphorus content were well within the recommended limits. The obvious remedy would seem to be slow cooling, or soaking at about 880 deg. C. At this temperature phosphorus migrates fast enough in alpha iron to redistribute itself quite uniformly throughout the iron matrix in a reasonably short time.

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### References

1. R. H. Heyer. "Gamma-Alpha Transformation in Wrought Iron." METALS & ALLOYS, Vol. 3, 1932, p 226.
2. J. H. Whiteley. "Distribution of Phosphorus in Steel Between the Points $Ac_1$ and $Ac_3$." *Journal*, Iron and Steel Institute, Vol. 101, Part I, 1920, p 359.

**Fig. 5. Magnification 400 Diameters.**

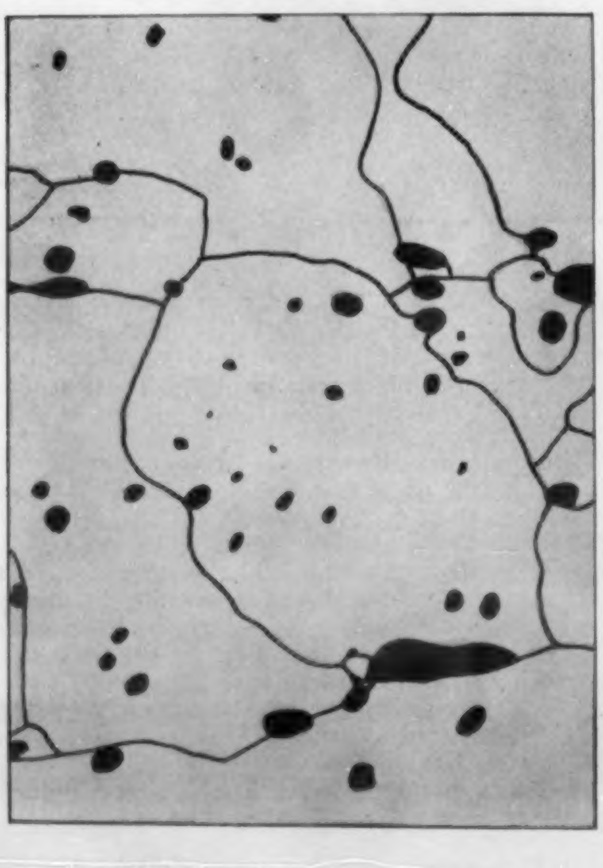


**Fig. 4. Magnification 400 Diameters.**

3. Subcommittee X on Research. "Quality Standards for Wrought Iron." *Proceedings*, American Society for Testing Materials, Vol. 34, Part I, 1934, p 129.

## A Statement in Reply

Our statement, "as Fig. 4 shows, this contained a very small amount of gamma," would have been better phrased had it read "this had contained." The islands are, of course, not retained austenite at room temperature.

Mr. Heyer's explanation of the duplex structure as related to the relative solubilities of phosphorus in alpha and gamma is in agreement with our own ideas. His indications that the islands are poorer in phosphorus than the ground mass are interesting. Scratch tests on such structures, and study of the path of fracture under impact, would be interesting in this connection.

So far as we know, the white areas in Figs. 7 and 8 are ferrite that has not transformed, while the darker areas consist of decomposition products of austenite.

We are grateful for Mr. Heyer's helpful comments.

C. H. LORIG AND D. R. KRAUSE

**Fig. 6. Magnification 400 Diameters.**

# Insulation of Open-Hearth Furnaces

## Survey of Results Obtained and of Materials Used

By EDWIN F. CONE

FOR A NUMBER OF YEARS the insulation of open-hearth furnaces has been a live topic. The idea, is a simple one in principle—if the escape of efficient heat, in any apparatus which depends on heat for its successful operation can be prevented or lessened, advantage should be taken of this fact. For years the insulation of steam pipes and other apparatus has been regular practice with many beneficial results.

At first the application of some form of insulation to open-hearth furnaces was extremely slow. Today, after several years of experimentation and trial in actual operation, the practice has become quite extensive and in the main the results have been highly satisfactory. This is particularly true regarding the effect on the life of the furnace and on the saving in fuel consumption.

In order to secure as complete a picture as possible of the general results of insulation, a questionnaire, reproduced herewith, was sent to steel companies and foundries operating open-hearth furnaces, asking for confidential replies. The present article is an analysis of these replies, without revealing the name of the company. It is sufficient to say, however, that the nearly thirty companies which cooperated include the leading large producers of steel ingots and of castings.

The presentation of the analysis follows the order of the nine questions which were answered, in many cases very fully. The first part of this article covers the experience of the companies in the use of insulation, and the second part, a description of some of the insulating materials used by different companies.

## Part I—Experience in Insulating Open-Hearth Furnaces

### Company No. 1

*Extent of Insulation.*—One of the largest steel companies reports that checkers are completely insulated above the floor line with 4 in. "Sil-O-Cel" concrete over existing red brick side walls; that roofs of checkers are insulated with 2½ in. insulating brick, and that checker chambers on new furnaces will be steel jacketed with complete insulation inside jacket.

As to uptakes and end walls, the slag pockets and end walls are completely insulated with 3 in. to 4 in. insulating cement which is also true of the ports.

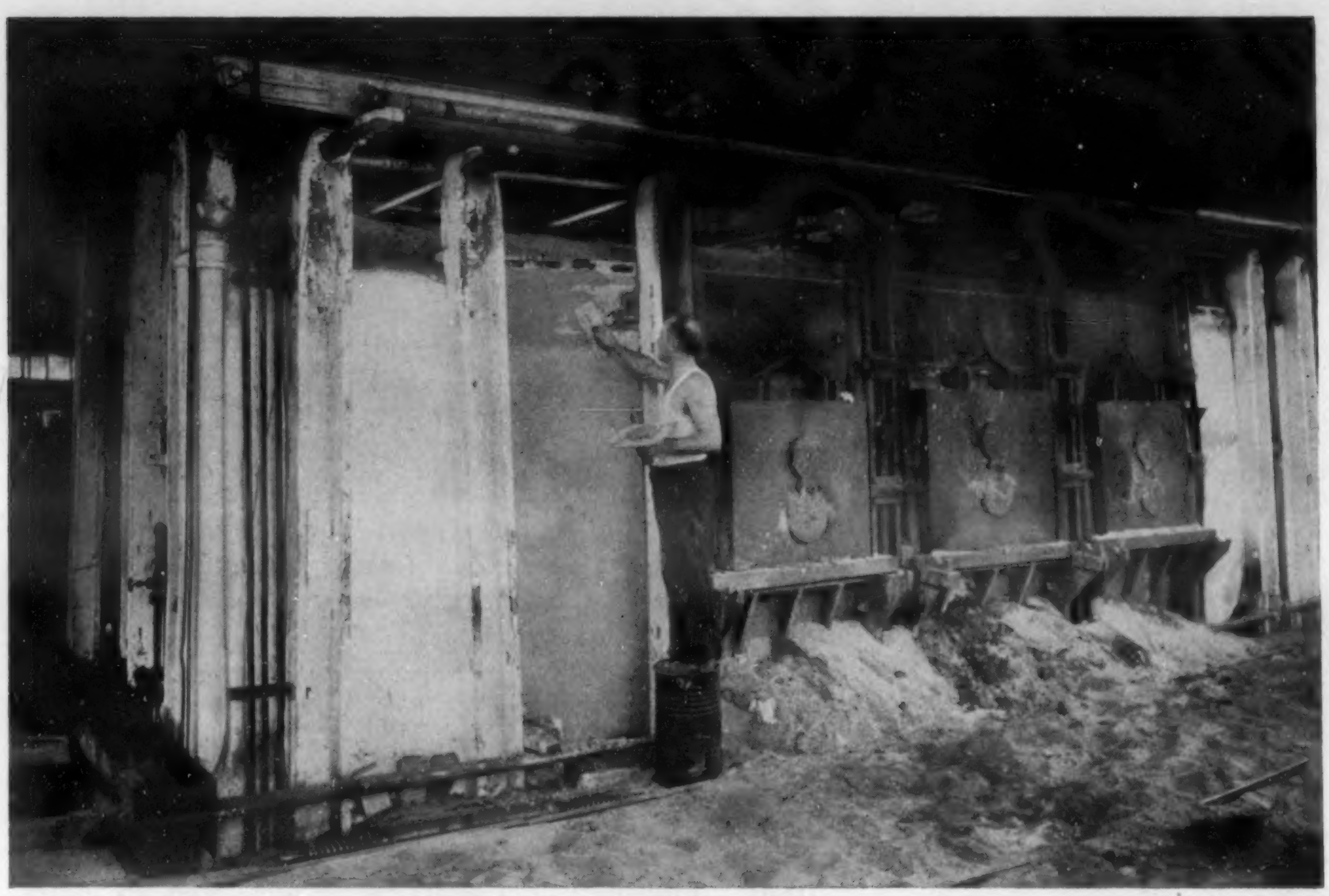
Roofs are completely insulated. A roof is first covered with 1½ in. silica sand mixed with a small percentage of lime or with ground silica brick. Over this is laid 2 in. to 2½ in. of mixed silica sand and pulverized cork or 2 in. to 2½ in. of slag wool. Over this is troweled about ¾ in. of insulating cement for hard, smooth finish.

*Furnace Life.*—It is the experience of this large company that the roof life of its open-hearth furnaces is about 30 per cent longer than before insulating, but that part of the credit for this increase might properly be given to roof temperature control. Care must be taken to prevent direct flame impingement on insulated brick at high temperatures and very high velocities at points where high temperature gases change direction should be avoided.

*Fuel Consumption.*—As compared to a period before any portions of the company's furnaces were insulated, the furnaces now operate at 70 per cent of their former fuel consumption. At least half of this saving is attributable to other improvements made at the same time with insulation—namely, control of draft and combustion, and elimination of air infiltration. The insulation is indirectly responsible for the latter, but it can be accomplished without insulating. The fuel saving accomplished by complete insulation above the floor amounts to 8 to 10 per cent.

### QUESTIONNAIRE ON INSULATION OF OPEN-HEARTH FURNACES

1. To what extent do you use insulation on open-hearth furnaces?
   (a) on checkers.
   (b) on uptakes or end walls.
   (c) on ports.
   (d) on roofs (slopes or entire surface).
2. What insulating materials do you use?
   If different materials on different parts of the furnace structure, please give details briefly—particularly *thickness.*
3. Reasons for use of different insulators.
4. Effect of insulation on life of furnace.
5. Effect of insulation on fuel consumption. If less fuel consumed, please give approximate data.
6. Effect of insulation on composition of steel in bath, particularly residual manganese.
7. Is water-cooling equipment eliminated to any extent?
8. Disadvantages, if any, in using insulators.
9. Additional experience or remarks.



Finish Coat of Insulation Being Applied to an Open-Hearth Furnace (Courtesy of Geo. F. Pettinos, Inc., Philadelphia).

No noticeable effect of insulation on the composition of the bath is reported and no water-cooling equipment is eliminated by the use of insulation.

*Disadvantages.*—This company reports no disadvantages from the use of insulation as described above. It states that more care is necessary by operators since more damage can be done in the same length of time to the surface of an insulated brick that is practically at maximum safe working temperature than to the surface of an uninsulated brick at the same temperature.

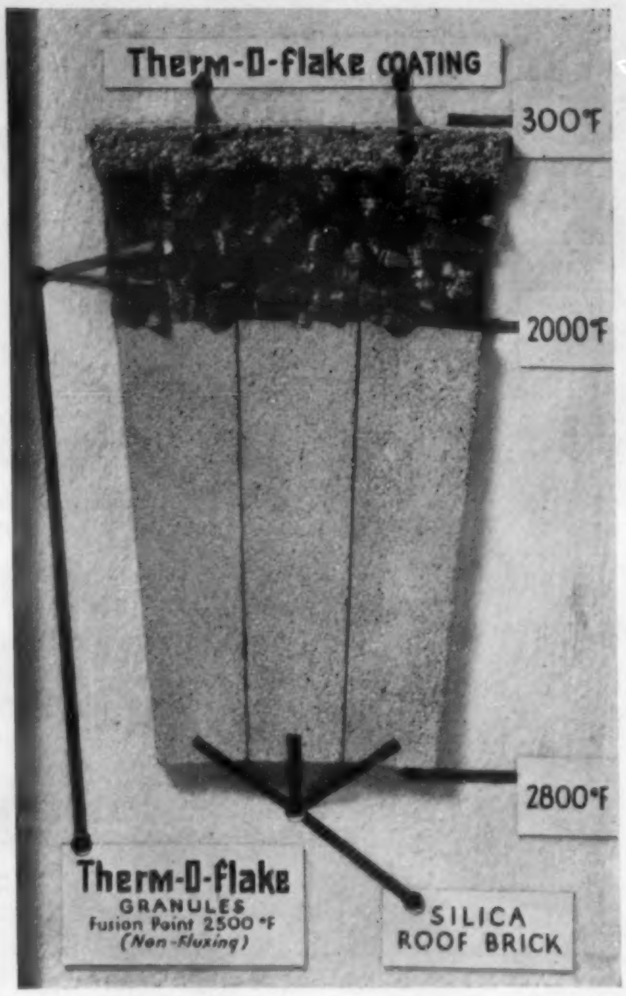
*Additional Experience and Remarks.*—Only completely insulated furnaces have been used by this company for two years. Furnaces have been insulated below the floors for six years. There has been roof temperature control almost continuously since roofs were first insulated; this is believed necessary to good roof life. Insulating cannot increase the safe working temperature and consequently cannot speed up the furnaces. Care must be taken to reduce the fuel input after insulating, particularly above the floor, as most of the radiation losses occur in this high temperature part of the furnace. After insulation, radiation losses are decreased and consequently fuel input must be lessened to prevent the furnace lining from exceeding its safe working temperature, and furnace end construction must be suitably modified to retain proper directional control of the flame with the reduced volume of gas or other fuel. The furnaces referred to in this report are all oil-fired with the exception of one on producer gas. The latter thus far has given no indication that complete insulation was not successful.

## Company No. 2

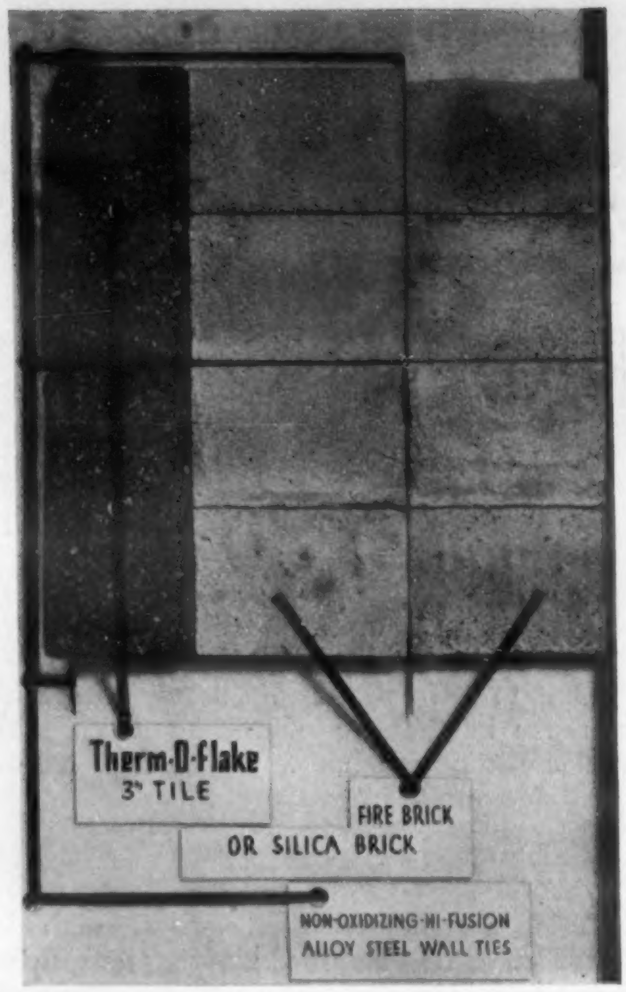
This company, a large producer of steel ingots,

Checker Chambers of an Open-Hearth Furnace Showing Insulated Cement Coating. (Courtesy of Geo. F. Pettinos, Inc., Philadelphia).

How "Therm-O-Flake" (Left) is Applied to the Roof of an Open-Hearth Furnace and Some of the Results Claimed. (Courtesy of Illinois Clay Products Co., Joliet, Ill.)




Typical Wall Construction of an Open-Hearth Furnace Using Therm-O-Flake Brick. (Courtesy of Illinois Clay Products Co., Joliet, Ill.)




uses insulation on the side walls and roofs of checkers and, on some of its many furnaces, on uptakes to the floor level. None is used on ports or on furnace roofs.

The insulating material used is blast furnace slag wool about 3 in. thick; one furnace is insulated with "Therm-O-Flake."

No change has been noted in the life of the furnace with insulation, all of it, below the floor level. On furnaces which had previously been completely sealed against air infiltration, there was no effect on fuel consumption; on other furnaces the fuel saving was about 5 per cent.

As to disadvantages, care must be taken on wide span checker roofs.

### Company No. 3

A large company, which has open-hearth furnaces at two large plants, makes the following comment:

*Extent of Insulation.*—On one furnace the checkers, uptakes or end walls and ports are completely insulated, but on six others the checker chamber walls and arches, slag pocket sidewalls and fantail arches are insulated. One roof of an entire furnace is insulated, while on another the roof is protected only to the slopes. "Therm-O-Flake" is the insulating material used. Its application is as follows:

On furnace roofs—3 in. of granules, 1 in. coating.
On slag pocket walls and bulkheads—2 in. coating.
On fantail arches—3 in. of granules, 1 in. coating.
On checker chamber roofs—2 in. coating.
On checker chamber walls and bulkheads—1 in. coating.

*In General.*—The company reports, for this one plant, that there has been no effect in fuel consumption or on the life of the furnace and composition of the bath. No disadvantages are listed but it is stated that the furnace heats up much sooner and retains the heat, which is especially noticeable during the "cleanout." Roof bricks are fused together and very few bricks are lost when cutting out for patch work.

At its other plant, the company states that insulation is used only on the checkers. Here two furnaces are insulated with Phillip Carey blocks, 2 in. thick, and eight are plastered with a mixture of 80 per cent pulverized asbestos and 20 per cent Portland cement, 2 in. thick. The checker chamber roofs are covered with dust from furnace flues, 2 in. thick, and this is covered with old fire brick to hold it in place. Plaster is much cheaper so more of it is used.

No effect in the life of the furnace has been experienced but there has possibly been a slight saving in fuel. Trials of insulation above the floor have been discontinued due to a shortening of the life of the walls when it has been applied. The general conclusion is that for proper results, furnaces should be completely insulated, including the roof.

### Company No. 4

A company which specializes in the production of high-grade steels in both electric and open-hearth furnaces, has the following to report regarding open-hearth furnaces.

*Extent of Insulation.*—On the checkers 4½ in. of insulating brick is used on side walls with 2½ in. of an insulating powder on the roofs. On the uptakes or end walls, 2½ to 4 in. of a plastic insulating material is applied below the floor level, and on the ports, 2 in. of insulating material is used. On the entire roof of the furnace 2½ in. of plastic insulating material is applied.

The insulating materials used are "Sil-O-Cel" brick, "Sil-O-Cel" powder and plastic "Wyolite." The reasons for the use of different insulators is dependent on furnace construction details, on the tempera-

ture to which they will be subjected and on the ease of application.

*In General.*—The use of this insulation practice has increased the refractory life of both the silica and fireclay bricks and has decreased fuel consumption 10 to 12 per cent. There has been no effect noted in the composition of the steel bath, nor has any water-cooling equipment been eliminated.

Accurate control of furnace pressure and combustion conditions must be constantly maintained by the operators.

### Company No. 5

A large producer of steel ingots in the East, which uses insulation only on checker chamber walls and roofs and not at all above the floor level, reports it is comparing different insulating materials. On one furnace it has 2 in. of "Sonnitep" and on another 2 in. of "J. M. No. 550" cement.

Due to only partial insulation, there has been no increase in the life of the furnaces. The reduced fuel consumption has approximated 1 gal. of oil per ton. No other effects are reported.

### Company No. 6

A large company which produces steel in Canada states that its open-hearth furnaces are completely insulated. On the checkers the insulating material is 4 in. thick; on the uptakes or end walls, 1½ to 2 in. thick; in the ports, 1½ to 2 in. thick and on the furnace roofs also 1½ to 2 in. thick. The material universally used is "Therm-O-Flake."

As to results in general, the life of the furnaces is increased and a fuel saving of at least 10 per cent is estimated. There has been no difference noted in the composition of the steel bath due to insulation, nor has there been noticed any reduction in the amount of water cooling. There are no disadvantages from insulation, but "a lot of advantages."

### Company No. 7

A large steel foundry which has been using insulation on its open-hearths for some years reports that for 14 years it has been insulating the checkers, for 12 years the uptakes or end walls, for 8 years the ports and since 1929 the hearth roofs. On the roofs of the checkers 5 in. of insulating material is used and on the side and end walls, 2½ in. On the furnace roofs insulating bricks are applied and on side and end walls a plastic insulation is used.

In general the testimony is that the use of this method of insulation has cut the cost for refractories in half and that there has been a saving in fuel of 25 per cent.

An interesting statement is to the effect that there has been an increase in residual manganese in the bath of 30 to 40 per cent. It is also pointed out that working conditions of the furnace operators have been decidedly improved.

### Company No. 8

A relatively small steel company states that, on the checkers, it applies 1 in. of an insulating material on the sides and 5 to 6 in. of blast furnace slag on the roof. No insulation is used on uptakes or end walls but on the ports, the outside only, 1 in. of insulating material is applied. The entire surface of the furnace roof is insulated with 3 in. of the insulating material on expanded metal lath supported by 2½ in. of insulating brick. Besides the blast furnace slag, the main insulating material is "Therm-O-Flake." In the selection of these, the question of cost and ability to reclaim has entered.

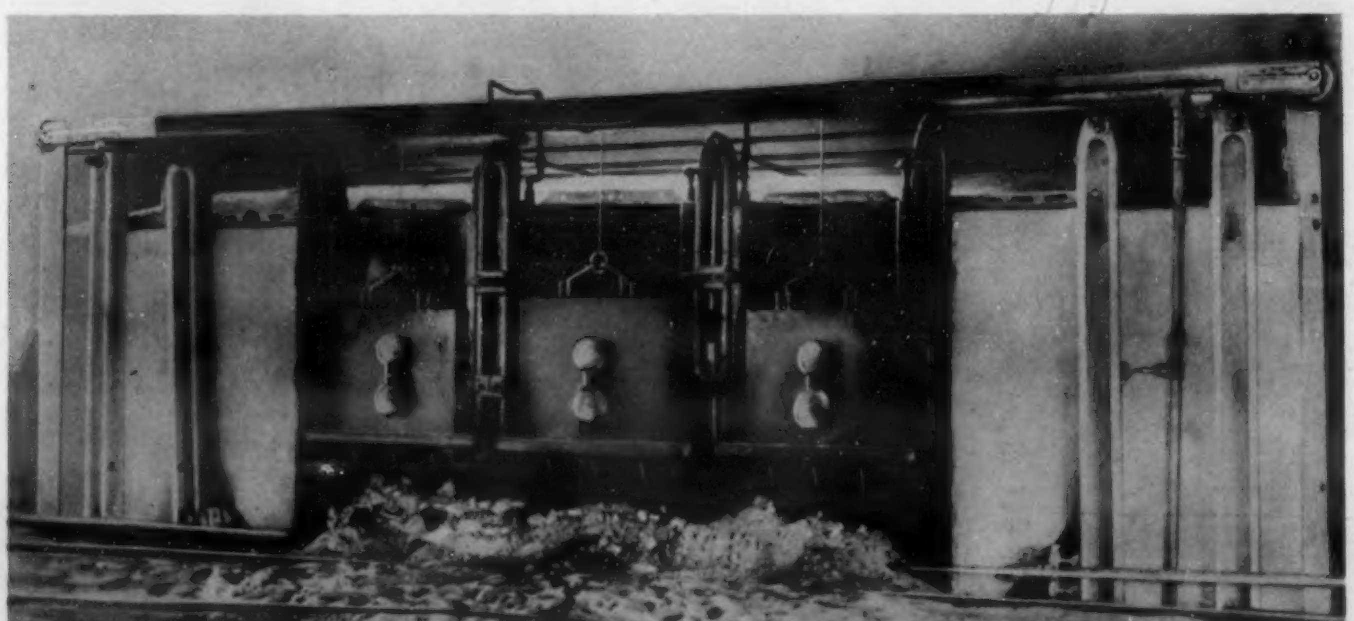
In general the company states that there has been an approximate decrease in fuel consumption of 10 per cent, but reports nothing on the effect on the life of the furnace. More care in furnace operation is said to be necessary, particularly so far as the roof is concerned. It is felt that insulation has materially improved the general operation of the furnaces and that there has been economy in refractory costs.

### Company No. 9

From one of the largest American companies producing steel ingots comes the following comment in reply to the questionnaire:

*Extent of Insulation.*—All checkers are completely insulated and the uptakes or end walls and the ports are insulated 3 in. thick. The entire roof has an insulation 4 in. thick. The insulating material used is "Therm-O-Flake."

*In General.*—The furnace life has been increased slightly and the fuel consumption has been decreased 5 per cent. There has been no noticeable effect on the composition of the steel bath, nor has there been any



**A Small Completely Insulated Open-Hearth Furnace in a Steel Foundry. (Courtesy of Geo. F. Pettinos, Inc., Philadelphia).**

elimination of water-cooling equipment. As to disadvantages, the company cites the danger of decreased roof life in the case of careless operators.

### Company No. 10

One of the large steel foundries of the country has supplied the following information: The checkers are insulated with insulating brick and the uptakes and end walls with a plastic material. No insulation is applied to the roofs. The insulating materials used are "Webers 48" and "Alumina." Practically the same thickness is applied for all materials, but price has been the governing factor.

The general effect has been a longer brick life and a reduction in fuel consumption of approximately 5 gal. of oil per ton of steel.

### Company No. 11

The results of the use of insulation on a very small open-hearth furnace are reported by a company producing steel castings.

Insulation is applied all over the checkers and on the uptakes or end walls, and the roofs are completely insulated. The thickness of the insulation varies from 1½ to 2½ in. The material used is "Sonnitep."

The effect of this insulation has been an increase in the life of the furnace of approximately 20 per cent, and the decrease in the fuel consumption has averaged 20 to 25 per cent, depending on the continuity of operations. Insulation requires more careful operation, which is considered an advantage.

### Company No. 12

From a small steel company producing ingots in the East, the following statements were received:

On the checkers 1½ in. of insulating material is put on the sides with 1½ in. of dry and 1 in. of wet material on the roofs. On the uptakes or end walls as well as on the ports, 1½ in. of insulation is applied. On the furnace roofs 2 in. of crushed brick is placed all over them and also 1½ in. of dry and 1 in. of wet insulating material. The insulation used is "Sonnitep."

From rather incomplete operating data thus far, the company states that the fuel saving has been from 33 to 39 gal. of oil per gross ton charged. Closer vigilance by operators is required and the regulation of air is vital with reversals more frequent.

### Company No. 13

A large steel making company which uses insulation rather extensively has the following comment to offer:

On the checkers 2 in. of insulation is put on the side walls and roofs and the same amount is applied to the uptakes or end walls. The ports are insulated, as is also the entire furnace roof. The insulating material employed is "Therm-O-Flake."

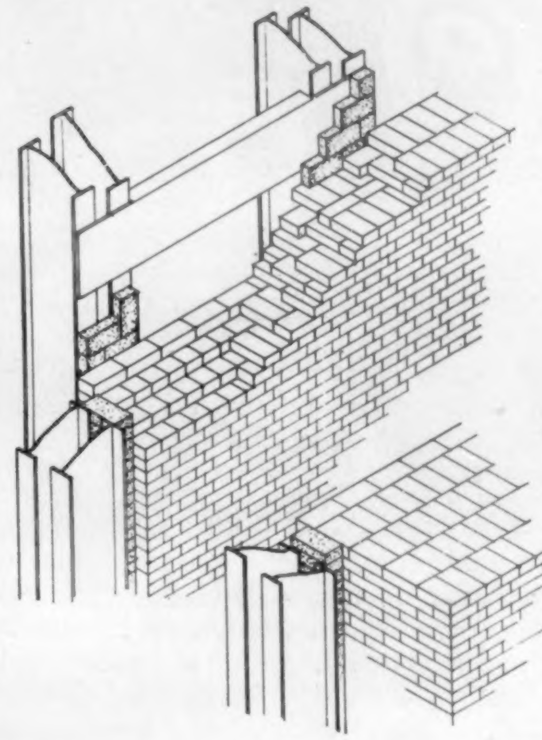
The roof life is reported to be the same with insulated or non-insulated furnaces, but there has developed an increase in the life of the end walls. A reduction of 5 per cent in fuel consumption has been the chief result.

### Company No. 14

One of the large steel companies operating in the East uses insulation quite extensively. It is applied to the checkers, the uptakes or end walls, and the ports. On the entire roof there is placed 2¼ in. of light weight silica brick, cemented at joints. The insulating materials reported used are "Kellog" and "Therm-O-Flake."

Not much difference has been noted in the life of the furnaces but there has been a fuel saving of about 2 gal. of oil per ton of steel produced. More attention is required of the operating men but the most benefit has been derived from a stoppage of infiltration of air through the furnace walls.

**Because Therm-O-Flake Insulating Brick Can Be Compressed under Great Pressure without Disintegration, Use is Made of this Property to Eliminate the Expansion Joints in the Wing Walls of an Open-Hearth Furnace where Silica Brick are Used. This brings the silica brick wall away from the buckstays and the insulating brick are placed between the silica brick and the buckstay as shown in the drawing (Courtesy Illinois Clay Products Co., Joliet, Ill.)**



### Company No. 15

Some interesting testimony comes from a steel company in one of the Middle Western states which uses insulation quite extensively.

On the side walls and over the arches of the checkers, 2½ to 3 in. of insulating material is placed with about 2 in. on the uptakes or end walls and on the ports. Roofs are covered with 4 in. of granules and 1 in. of insulating coating. The brand of insulating material used is "Therm-O-Flake."

From the experience of the company with insulation of this character and extent, it has been found that the life of the brick work has been augmented from 10 to 15 per cent, and that fuel consumption has been decreased about 10 per cent.

### Company No. 16

From a second Canadian producer of open-hearth steel ingots comes the following recital of experience:

On the checkers 1½ in. of insulating material is placed on the side walls and the same procedure is carried out on the uptakes or end walls of the furnace. The roofs of the furnaces are insulated with a total of 5 in. of material—2½ in. of this being granules and 2½ in. of a coating material. The type of insulation used is "Therm-O-Flake." It is stated that the granules withstand a higher temperature than the coating and that the brick are easily recovered and used again.

Increased life of the furnace has been the result of this practice and the decrease in fuel consumption has been about 200 lbs. of coal less per ton of steel used, producer gas being used. The only disadvantage

mentioned is that the use of insulation makes it a little more difficult for bricklayers to patch roofs because the bricks bond more in an insulated furnace.

### Company No. 17

A large producer of steel in the Middle West uses insulation quite extensively and recounts the following experience:

*Extent of Insulation.*—On the checkers 4 in. of a "C-3" cement, 4 in. of "Dicalite" and 2 in. of "Therm-O-Flake" are used, while on the uptakes and end walls there is placed 4½ in. of "H. & W. 444" brick, 2 in. of "Therm-O-Flake" and 2 in. of "Eagle Picher 111." No insulation is applied to the ports, but on the entire surface of the furnace roofs there is placed 2½ in. of "H. & W. 444" brick.

*In General.*—No data are yet available as to the effect of this insulation on the life of the furnaces, but thus far there has been a saving in fuel consumption of approximately 5 to 10 per cent. Among disadvantages are mentioned extra cost for repairs and extra care in operating.

### Company No. 18

A small company in Pennsylvania, which produces high grade open-hearth and electric alloy steels, uses insulation only on the checkers and on the uptakes to the floor level. Against the plates of both the checkers and uptakes, 4½ in. of "Sil-O-Cel" brick are installed. The checkers have been insulated since the furnaces were installed.

No tangible effect on the life of the furnaces has been observed and there has been a decrease in fuel consumption of not more than 1 per cent since insulating the uptakes.

At one time two courses of an insulating brick were put on the flat on the 9 in. roof of the furnace. These had to be removed because the brick became so hot they started to slip out of the crown of the arch. The brick company said that the temperature at which silica brick lose their crushing strength had been exceeded.

### Company No. 19

One of the four largest producers of steel ingots in the United States naturally presents an interesting survey. Like all these large companies it has many open-hearth furnaces. It states that, as a whole, based on experience at various plants, insulation of furnaces below the floor level is routine practice, but that complete insulation above floor level is yet largely in the experimental stage. Some of the salient points in this company's reply are condensed in the following:

*Extent of Insulation.*—Checker chambers are completely insulated, including checker chamber side walls, roofs, bulkheads, etc., although some plants find it desirable not to insulate tail roofs. In some instances the checker chamber bulkheads are merely sealed rather than insulated. Uptakes and end walls above floor level are usually insulated. The bulkheads of ports are also insulated.

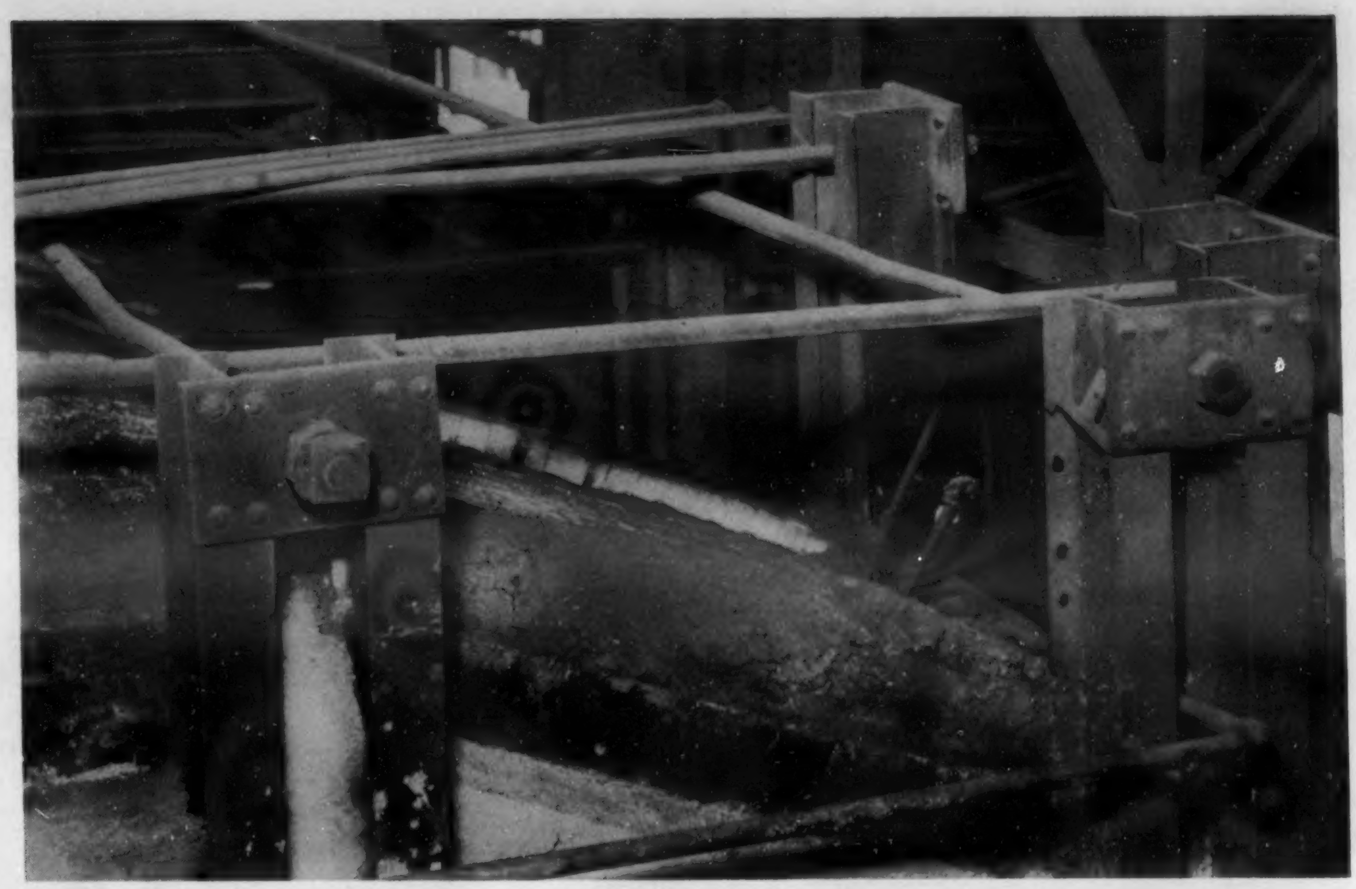
As to insulation of furnace roofs, experience has varied, some promising results having been obtained. In some cases greater roof maintenance problems have been encountered, resulting sometimes in increased rather than decreased over-all net cost. Some plants insulate slopes of the furnaces, but not the main roof, while others insulate both the main roof and slopes. In some instances merely sealing is resorted to. The company regards complete insulation of furnace roofs as still in the experimental state.

*Insulating Materials.*—Several factors enter into the choice of insulating materials: The purpose for which they are intended; the temperatures of the various parts of the furnace system to be insulated, whether vertical or horizontal surfaces are involved; whether strength of these materials is necessary, etc.; and, in the case of the main roof insulation, whether these materials will or will not flux with silica brick of the roof. Many types of insulating materials adequately serve the purpose, states this company, at least on most parts of the furnace walls or system, and it hesitates to specify the names or characters. No general rule can be laid down as to the thickness of the insulation, this varying with the wall thickness, temperatures, construction, type of furnace, method of operation, and so forth.

*Furnace Life and Fuel Consumption.*—Complete insulation may be said to have resulted in a somewhat increased roof, bulkhead, end wall life, etc.; the magnitude of these savings depending largely upon the character of results previously obtained. In some instances plants have found maintenance problems of roofs increase with roof insulation in spite of adequate design and operation. such plants insulating all parts of the furnace system, except the roof.

**A Large Open-Hearth Furnace Completely Insulated (Courtesy of Illinois Clay Products Co., Joliet, Ill.)**

Tuyere Type Thermocouple Installed in Bulkhead Roof of Open-Hearth Furnace at Lukens Steel Co., Coatesville, Pa. (Courtesy of Brown Instrument Co., Philadelphia).



Due to the physical changes in the structure of roof brick under insulation, and with particular respect to silica brick in the main roof, less spalling may be expected and, other things being equal, an improved roof life may be assumed. It cannot, however, be stated, says this company, that roof insulation guarantees increased roof life, since this question is still largely to be determined by further tests and investigations. It is pointed out that final conclusions cannot be drawn at this time in view of the character of operations during the past several years.

As to fuel consumption—where insulation of furnaces (and particularly main roofs) has not been accompanied by fluxing of brick and thereby in extensive repairs and shutdowns, definite fuel economies have been obtained, amounting in some cases to as much as 10 per cent.

*Disadvantages.*—When furnaces have been previously well designed, the intelligent use of insulation may result in economies. Excessive insulation of checker chamber roofs or of main roofs may prove detrimental. If clay bricks are used in checker chamber roofs and insulated excessively, sagging of the bricks and, finally, collapse of this roof may result. Incorrect materials or application to roof insulation may also result in decided disadvantages due to fluxing of the main roof with the insulation. Excessive insulation of the roof may result in shorter roof life due to excessive temperatures. Even moderate insulation may result in damage to the roof where operating temperatures are close to the critical range of the roof brick. To some extent the same problems are presented in proper insulation of end walls and bulkheads above floor level. Another problem is the maintenance of insulation on vertical walls where furnaces are subjected to long or intermittent shutdowns; in many cases such insulation cracks and no longer adheres to the furnace walls.

In general the company believes that under-insulation is preferable to over-insulation.

### Company No. 20

Another company which uses insulation quite extensively furnishes the following comment:

On the side walls of the checkers 1½ in. of "Therm-O-Flake" cement is applied with 2 in. of the same brand of granules and 1 in. of the same cement on the roofs. On the uptakes or end walls 2 in. of this cement is put on while on the ports 2 in. of cement is placed on the side walls and 3 in. of granules and 1 in. of cement on the roofs. The enaire surface of the main roofs of the furnaces is covered with 3 in. of the granules and 1 in. of the same cement. As indicated, only "Therm-O-Flake" granules and coating cement are used. The reason for using these two forms of insulation is application on horizontal and vertical planes.

As to the effect on the life of the furnaces, no difference has been detected between insulated and uninsulated furnaces. There has, however, been a saving in fuel consumption of about 10 per cent.

### Miscellaneous Reports

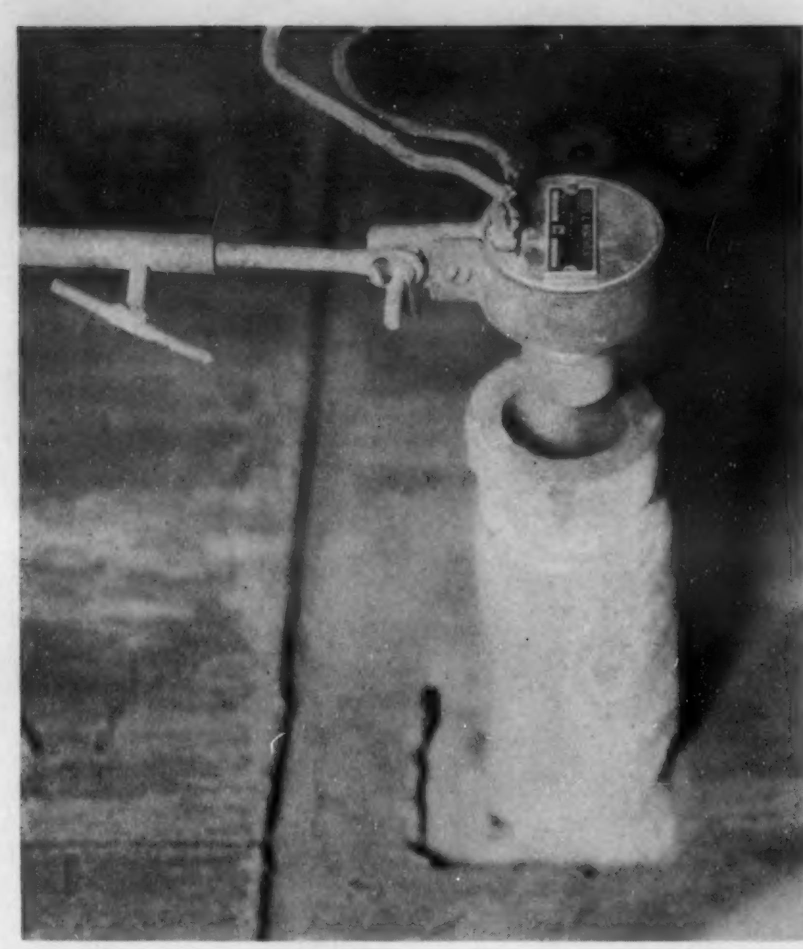
Incomplete reports from several companies are to the following effect:

An insulating cement applied to side walls and roofs of checkers, 1¾ in. thick, showed no appreciable fuel saving. The first time the furnace was shut down, the insulation pulled away from the side walls. No other parts of the furnaces were insulated.

Another report states that insulation is used on the checker, the end walls, the side walls and the roof of the furnace. The material on the roof was put on 4 in. thick. "Therm-O-Flake" was used. Operations have been over so brief a time that worthwhile conclusions cannot be stated. Thus far the heat-up period seems to have been shortened.

In another case insulation is applied to the checkers, uptakes or end walls, ports, but only on the slopes of the roofs. "Therm-O-Flake" is used. No difference has been noted in the life of the furnaces but a saving in fuel consumption of about 3 per cent is reported.

Another company uses "rock wool" as an insulating material on the checkers but operations have not been of long enough duration to furnish tangible results.



**Installation of Recording Apparatus for Temperatures of Uptakes Where Thermotube is Looking into a Closed-End Tube (Courtesy of Leeds & Northrup Co., Philadelphia).**

### Special Testimony

From a man who has had wide experience in open-hearth operating practice, the following extracts from his comments are of interest:

Insulation of checker chambers has been 100 per cent since 1924 or 1925 and for the past 3 or 4 years it has been 100 per cent on uptakes or end walls and on ports. As to main roofs of furnaces, insulation has been up to 100 per cent depending on many factors of design and operation. As to insulating materials, these have been divided into five classifications, based on structural factors.

No change can be proved, he says, as to any effect of insulation on the life of a furnace unless all factors, including design and operation of a particular furnace, are included. If, as a result of insulation, the furnace may be operated at higher temperatures, which is doubtful, then a small saving in residual manganese in the bath is possible; otherwise, none.

As to any disadvantages, this authority says that the time for hot repairs is greatly increased by insulation, due to the slower rate of cooling of the furnace. If the furnace is of "abridged fundamental design," insulation may increase maintenance costs.

### Summary of the Reports

FROM the foregoing general presentation of the reports of some thirty steel ingot and steel foundry companies, which operate several hundred open-hearths, it is evident that the application of insulation is by no means uniform as to the extent of its use on a furnace. Some apply it only to checkers, others to checkers and other parts except the roof. No small number use insulation on the entire furnace. It seems evident from the analysis of these reports that more benefit is obtained when insulation is extensive, rather than only partial, though there are beneficial results in all cases.

Advantages of insulation which are most important center in the effect on the life of the furnace and in the savings in fuel consumption. One large company reports an increase of 30 per cent in furnace life with insulation complete. A small steel casting company reports an increase in life of approximately 20 per cent with the entire furnace insulated. A large plant producing ingots states that the increased life of brick work has been 10 to 15 per cent with insulation complete. Another open-hearth plant testifies that insulation of the whole furnace has cut the cost of refractories in half. Other companies report anywhere from no benefits to moderate increase of furnace life.

When it comes to the effect on fuel consumption the evidence of the advantages of insulation is more positive and general. A very large company says that with complete insulation, the fuel saving has been 30 per cent, while another large producer reports 10 per cent saving. A small steel foundry has found its fuel saving to run as high as 20 to 25 per cent, while another much larger foundry puts the saving at 25 per cent, insulation being complete in both cases. Six other plants report fuel savings of 10 per cent, while four others estimate it at 5 per cent or more. All but one of the companies whose reports are analyzed, testify to some reduction in fuel consumption.

Only one company mentioned the better working conditions for the men, but this fact is an impressive advantage, subscribed to by anyone who has been in plants where insulation is extensive.

Insulation of open-hearth furnaces has come to stay. Many problems need yet to be worked out, but the advantages of the use of proper insulation outweigh the disadvantages. In the opinion of one prominent open-hearth superintendent, within a few years furnace operators who do not insulate their furnaces will be behind the times.

## Part II—Some of the Insulating Materials

MANY materials which are suitable for insulating open-hearth furnaces have been mentioned as used by the various steel companies. Some of these and others are briefly described in the following paragraphs.

### Sonnitep Insulating Cement

This material is described as composed of mineral fiber, not slag or rock wool, according to the producer, George F. Pettinos, Inc., Philadelphia. It lacks the undesirable qualities of slag or rock in respect to high temperature insulation. This insulating cement is wool of a high silica content which makes it adaptable where there are temperatures up to 2,000 deg. F. without any chemical reaction with refractory materials. It melts at approximately 2,600 deg. F. It is over 90 per cent mineral fiber. The material mixed with the fiber is a bond which makes the cement easy to apply as a plastic cement when mixed with water, requiring no reinforcement. It is claimed to have practically the same insulating value as the plain rock wool or slag wool. It can be applied to iron, steel, brick, etc., without reinforcing, and will not crack, shrink or peel.

### Therm-O-Flake Products

Under the trade name "Therm-O-Flake," the Illinois Clay Products Co., Joliet, Ill., produces three different products: "Therm-O-Flake Granules," "Coating" and "Brick."

The granules are carefully selected expanded vermiculite granules of a special analysis and special screen grading. They weigh about 5¼ lbs. per cu. ft. on the furnace, and have a fusion point of approximately 2,500 deg. F. They are claimed to be free from any tendency to flux with the brickwork, even when they are molten. The granules are applied loose and dry, and are so light that no important load is placed on the brickwork. They are usually spread on the silica brick of a roof 3 in. deep; covered later with a 1 in. layer of coating.

The Therm-O-Flake Coating is a dry fluffy aggregate, composed of specially selected vermiculite granules blended with a special mineral fiber and bond. Mixed with water, it is plastered on the brick surfaces. The material weighs about 15 lbs. per cu, ft. on the furnace and has a fusion point of about 2,300 deg. F. It is used to insulate the vertical walls.

The bricks of this same trade name are very light, the standard 9 by 4½ by 2½ in. straight, weighing only 18 oz. They are made of vermiculite granules blended with special refractory fibers and bonds. They undergo no volume change when heated up to 2,000 deg. F. and have a fusion point of approximately 2,400 deg. F.

The company states that it has supplied these insulating materials to over 200 open-hearth furnaces in the United States and Canada, of which 160 have been main roof installations.

### An Insulating Fire Brick

From Mexico, Mo., comes some information from the A. P. Green Fire Brick Co., regarding an insulating fire brick—"G-25."

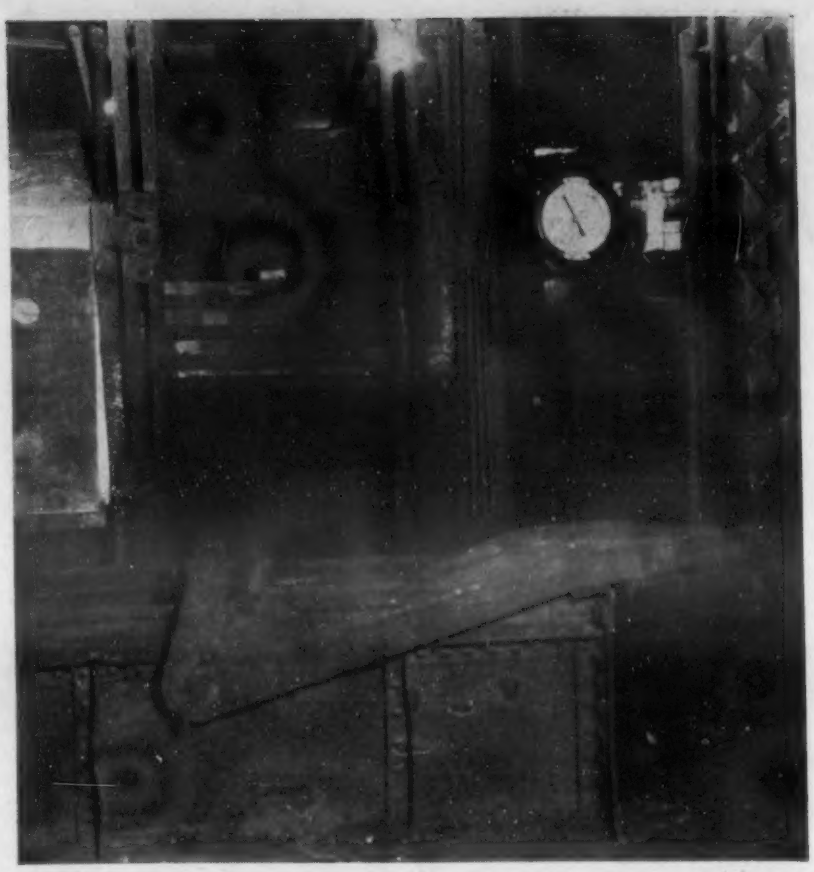
This brick is composed of 100 per cent Missouri fire clay and it has a density of 42 lbs. per cu. ft. Its cold crushing strength is 350 lbs. per sq. in. The hot load panel test on this brick is 8 lbs. per sq. in. at 2,500 deg. F. with no deformation. G-25 is extremely light —2½ lbs. Furnaces equipped with this brick are said to be brought up to temperature in one-fifth the time of ordinary fire brick with heat losses through furnace walls greatly reduced and with fuel costs cut as much as 50 per cent.

### Another Insulating Brick

Armstrong's 2,500 deg. high temperature insulating brick is furnished by the Armstrong Cork Products Co., Lancaster, Pa., in five different thicknesses—1½, 2, 2½, 3 and 4½ in. These brick are described as standing 2,900 deg. F. before softening, being of a silica base and not causing any fluxing in silica brick.

In using this brick for insulation on open-hearth furnaces, the most efficient job is to completely rebuild the furnaces above the floor making the inside walls the usual 13½ in. of silica brick thickness and laying a 2½ in. Armstrong brick on edge in front of the buck stays between the top of the pan and the underneath edge of the channel iron holding the skewback. The insulated panel of the proper thickness used between these insulated buck stays form a uniform insulated wall.

In roof insulation 2½ or 4½ in. of this brick are laid dry and tightened up after the furnace has come to temperature, this grouted in place which is described as giving somewhat of a secondary arch, allowing for the silica brick to expand and contract without each time cracking the insulated covering. Another roof construction used successfully consists of 12 in. of silica brick, 1 in. silica sand over this roof before applying Armstrong insulating brick.



Typical Installation of the Round Chart near the End of an Open-Hearth Furnace which Directly Indicates the Temperatures in the Roof or Elsewhere (Courtesy of Leeds & Northrup Co., Philadelphia).

### Products of a Large Company

A variety of products made by the Johns-Manville Corp., New York, has been found satisfactory for insulating open-hearth furnaces. A brief description of these follows:

*Vermiculite Products.*—Perhaps the easiest material to apply to a furnace roof is "J-M Vermiculite Granules." This consists of uniformly expanded mica, graded in size and light in weight, which can be easily spread or raked over the roof to about 2 in. in thickness. In order to reduce the infiltration of air through these, a coating of approximately ½ in. in thickness of a vermiculite cement, "J-M No. 500" is applied over the granules. While this has the basic characteristic of the granules, it contains, in addition, asbestos fiber and a binder so that it will form a coating over the granules, thus reducing the permeability. This cement is also sometimes used alone when it is moistened just enough to make it cohesive and then spread over the roof to a thickness of about 2½ in., or it is finished with a ½ in. coating applied as a cement.

*Superex Blocks.*—The use of "Superex Blocks," composed largely of diatomaceous earth, is claimed to have a distinct advantage because this is the lowest in permeability of all the materials in general use. The blocks are furnished 6 in. by 36 in., making their application to a roof a simple matter. They are ordinarily used 1½ in. thick.

*Sil-O-Cel Monolithic Insulation.*—This material is a diatomaceous earth powder mixed with a small amount of binder to prevent the shifting or moving of the powder after installation. Here again the ma-

**Radiation Pyrometer on Air Jacket on Open-Hearth Roof at the John A. Roebling Son's Co., Trenton, N. J. (Courtesy of Brown Instrument Co., Philadelphia).**

terial is mixed with water or raked in place and then lightly tamped to the desired thickness of about 2 in. Having a binder in it and being lower in permeability than "Vermiculite Granules," is can be salvaged at the end of a roof's life, remixed with new material and used again. Another advantage is that excessive temperatures, due to a very thin roof, have no serious effect on its insulating value.

*Sil-O-Cel Brick.*—Some prefer insulation in brick form and use "Sil-O-Cel C-22 Brick," composed of calcined diatomaceous earth, laid over the roof. Though least used because of its high first cost, it has the highest salvage value.

The foregoing refers to main roofs. As to the side and end walls above the charging floor, "Vermiculite Cement" is used to a thickness of about 2 in. In some of the newer steel encased furnaces, "Sil-O-Cel Super Brick" are used between the steel casing and the furnace brickwork. The company states that, for insulation below the floor, "Superex Blocks" and "Sil-O-Cel Brick" are widely and successfully employed for insulating regenerators, flues, slag pockets, etc.

### Products of a Large Refractory Company

Some open-hearth operators prefer, says the Harbison-Walker Refractories Co., Pittsburgh, brick insulation over bulk insulation for main roofs. This company's "HW444" and "HW-111" have been given some consideration. The most economical is probably "HW-111." This brand has been used successfully for the insulation of open-hearth bottoms with 4½ to 5 in. placed directly upon the pan, having the insulating effect of about 15 in. of dense fireclay brick. "HW-111" is pointed to as exceedingly strong mechanically, its cold crushing strength being over 450 lbs. per sq. in.

Below the floor, the "HW-777" brick and "Calag," a diatomaceous earth aggregate for the preparation of insulating concrete, have had extensive applications, says the company. Above the ground line the regenerator walls are frequently insulated with 4½ in. of "HW-777" brick. Below the ground line the same brick are also used if protected from moisture.

### A Plastic Cement

Under the trade name "Ada-stic," the Botfield Refractories Co., Philadelphia, offers a plastic insulating cement for open-hearth furnaces. The base of this material is a specially processed strong mineral fiber. Combined with this base are a number of other ingredients, the combination of which is claimed to produce adhesiveness, lack of shrinkage, easy working qualities and unusual efficiency. The use of this cement is claimed to result in a reduction of heat loss through furnace walls with less fuel consumption and more rapid heating up.

### Insulating Brick

Five brands of insulating brick are produced by the Babcock & Wilcox Co., New York: "B. & W. K-30," "K-26," "K-22," "K-20" and "K-30-3." The last one is a brick weighing 3 lbs. and designed for those special service conditions requiring a more rugged insulating firebrick of high refractoriness than the K-30 type. All five possess every advantage of an efficient insulator and, due to their high fusion points, freedom from shrinkage and inherent ability to support loads under temperatures, may be used as the furnace lining, directly exposed to heat.

## Temperature-Limit Control

BEARING on the whole subject of insulation, particularly of the main hearth roofs of furnaces, is a comparatively recent development. It is the perfection of equipment for temperature-limit control for furnace roofs. Two leading companies, producing temperature measuring equipment, have developed special apparatus which is now standard. It is pointed out that furnace roofs can now be protected from over-heating by the use of such equipment.

The apparatus offered by the Leeds & Northrup Co., Philadelphia, is described as outstanding in simplicity, easy to use, built for rough service and requiring minimum maintenance. It consists of four units: A block of silicon-carbide; a thermotube with suitable mounting; a "Micromax Model R" recording controller and an automatic valve in the fuel line. This apparatus, part of which is installed in the furnace roof, shows the operator the temperature of the roof at all times and gives him automatic protection in emergencies.

Whether roofs are insulated or not, it is claimed that this apparatus guards against over-heated conditions, prolongs the life of the roof and enables continuous operation at the highest safe temperatures. At one prominent steel plant, the superintendent insulated his furnace, installed the apparatus and in the very first campaign increased the number of heats over 125 per cent.

Another company which provides apparatus for similar purposes is the Brown Instrument Co., Philadelphia. A general description of this was published in METALS AND ALLOYS, December, 1935, pages 333-335. This equipment uses thermocouples installed under the insulation of the roof or in a carborundum block in the roof itself. Equally beneficial results are reported.

So much for insulating materials and special temperature controlling apparatus. The phase of the problem of insulating open-hearth furnaces is yet in the experimental stage. Just which material is best for insulation depends in many cases on the design of the furnace and on operating conditions. Great progress has been made in recent years in the perfecting of such materials and equipment. It is highly probable that still greater progress is in store.